44TH CONGRESS, 2d Session. } SENATE. { Ex. Doc. No. 37.

REPORT OF THE SUPERINTENDENT

OF THE

UNITED STATES COAST SURVEY

SHOWING

THE PROGRESS OF THE WORK

FOR THE

FISCAL YEAR ENDING WITH

JUNE, 1876.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1879.

LETTER

OF

THE SECRETARY OF THE TREASURY,

ACCOMPANYING

THE REPORT OF THE SUPERINTENDENT OF THE UNITED STATES COAST SURVEY FOR THE YEAR ENDING JUNE 30, 1876.

DECEMBER 21, 1876.—Ordered to lie on the table and be printed.

TREASURY DEPARTMENT, *December* 19, 1876.

SIR: I have the honor to present for the information of the Senate a report made to the department by Carlile P. Patterson, Superintendent of the United States Coast Survey, stating the progress in that work during the year ending June 30, 1876.

Very respectfully,

L. M. MORRILL,
Secretary of the Treasury.

Hon. T. W. FERRY,
President of the United States Senate.

ABSTRACT OF CONTENTS OF REPORT.

CONTENTS OF APPENDICES.

ALPHABETICAL INDEX.

C.

D.

E.

Q.

R.

S.

T.

U.

V.

W.

REPORT.

UNITED STATES COAST SURVEY OFFICE,
Washington, December 2, 1876.

SIR: I have the honor to present this detailed report on the progress made in the survey of the Atlantic, Gulf, and Pacific coasts of the United States during the year which ended June 30, 1876. The report will contain, as usual, separate notices of the work done in the localities to which parties were assigned, and in general the statements will conform in respect of arrangement with the geographical order observed in the following abstract, a copy of which was transmitted to the department in October last.

Field-operations in the course of the fiscal year ending June 30, 1876, have included deep-sea soundings between the coast of Maine and George's Bank; development of a rock near Jeffrey's Ledge; survey of islands between Isle au Haut and Mount Desert, and of the western shore of Blue Hill Bay; soundings in Isle au Haut Bay; topography of Northern Bay near Castine, including the head of Bagaduce River; and of the Penobscot River above Bucksport; tidal observations at North Haven, Penobscot Bay, Me.; revision of sailing-directions for Coast Pilot, and views for charts between Eastport and Penobscot entrance; observations for determining the coefficient of refraction near Camden, Me.; triangulation in New Hampshire; soundings near Fletcher's Neck, off Old Orchard Beach, and at Saco River entrance; tidal observations at Boston, Mass.; determination of positions of life-saving stations along the New England coast; soundings near Duxbury Pier Light and Manomet Point, Mass.; research relative to deposits in Plymouth Harbor; hydrography of the eastern approach to Nantucket Sound, and near Monomoy Point, Mass., also of the southern part of Handkerchief Shoal, Vineyard Sound, Mass.; topography of Taunton River between Mount Hope Bay and Weir Village, Mass.; tidal observations at Providence, R. I.; determination of light-house positions between Hyannis and Greenport, N. Y.; triangulation of Connecticut River up to Hartford; topography adjacent to New Haven Harbor; development of Cumberland Shoal, east end of Long Island, and of the passage between Gull and Plum Islands; triangulation near the boundary between New York and Massachusetts; revision of sailing-directions, and views of harbors and landings in Long Island Sound and the Hudson River; shore-line survey of New York Harbor from the Narrows to Astoria and from Castle Point to Bull's Ferry; physical researches and observations, including current observations in Hudson and East Rivers and New York Harbor, and development of Shrewsbury Rocks, coast of New Jersey; tidal observations in New York Harbor; latitude and azimuth determinations at Beacon Hill, N. J., and connection of primary station point with triangulation of New York Harbor; hydrography of Fire Island Inlet, N. Y.; triangulation of south coast of Long Island between Babylon and Far Rockaway, and topography east and west of the former; also at the eastern end of Great South Bay; tidal observations at Sandy Hook; topography of Barnegat Bay and vicinity of Tom's River; reconnaissance for triangulation in Northern New Jersey, and in the Lehigh Valley, Pa.; hydrography of the Delaware River and development of a ledge between Marcus Hook and Chester, Pa.; location of range-light on the New Jersey side of same river above Liston's Tree, and topography of sites for others on the west side of the river near the last-named point; reconnaissance for triangulation in southeast part of Pennsylvania; physical hydrography of Norfolk Harbor and adjacent waters; tidal observations at Fortress Monroe, Va.; topography of portion of Smith's Island, on the boundary between Maryland and Virginia; lines of level between Washington and Annapolis; magnetic observations at Washington; triangulation of James River, Va., from City Point to Richmond, and in the same State southward along the Blue Ridge, including determinations of latitude and azimuth; reconnaissance for triangulation along the Blue Ridge, south

and west of Lynchburg, Va., and in West Virginia; hydrography of Pamplico Sound, N. C., along the western side north to Stumpy Point; survey of Alligator River from previous limits south to Blunt's Canal; latitude, azimuth, and magnetic observations at Sand Island, in the northern part of Pamplico Sound; hydrography of Core Sound, N. C., and of Winyah Bay and Georgetown Bar, including the mouths of the Pedee, Waccamaw, and Sampit Rivers; soundings near Edisto Island and at the north end of Hunting Island, S. C.; triangulation near the boundary between South Carolina and Georgia; hydrography of Fernandina Bar, Fla.; reconnaissance of Saint John's River, Fla., from Jacksonville to Lake Monroe, and triangulation and shore-line survey from Jacksonville to Mandarin Point; survey of Indian River, Fla., southward to near Cape Canaveral; hydrography of Key Biscayne Bay, and sailing-lines for channels across Florida Reef; triangulation of Sarasota Bay, Fla., and topography of Hillsboro' Bay; hydrography of coast near Sarasota Bay, and of Hillsboro' Bay; detailed survey of Gulf coast of Florida, from Suwanee River to Bowlegs Point; hydrography of Appalachee Bay, east and west of the approaches to Saint Mark's Harbor, and soundings in Saint Joseph's Bay; hydrography of the northern coast of the Gulf of Mexico between Saint Andrew's Bay and Mobile Bay; triangulation near the boundary between Northern Georgia and Alabama, and reconnaissance in the latter State to continue triangulation west of the Atlanta base-line; triangulation in Southeastern Kentucky; deep-sea soundings in eastern part and across the Gulf of Mexico, with observations on currents and for temperature and density; special survey of Cubitt's Gap and Southwest Pass (Mississippi delta), with current and tidal observations; triangulation and topography of same localities; reconnaissance for survey of Barataria Bay, La.; tidal observations at New Orleans; survey of Mississippi River from Oakland to Reserve Plantation, and special examination of Bonnet Carre crevasse; triangulation in Wisconsin between Prairie du Chien and Madison; soundings completed in Copano Bay, Saint Charles Bay, Aransas Pass, and Corpus Christi Pass, Tex.; reconnaissance for triangulation of Laguna Madre, Tex.; tidal observations completed at Saint Thomas, West India Islands; reconnaissance for primary triangulation between San Diego and San Pedro, Cal.; survey of the vicinity of Santa Monica and of the adjacent coast of California; soundings in the vicinity of Santa Rosa and San Miguel Islands; inshore hydrography near Point Dume, and survey of Santa Monica Bay; triangulation of the western part of Catalina Island; latitude and azimuth determined near Point Concepcion, Cal.; triangulation across the Santa Barbara channel to Santa Cruz Island; triangulation and topography of coast between Point Sur and Monterey Bay; tidal observations at Fort Point, Cal.; current observations in San Francisco Bay; hydrography of Mare Island Strait and Karquines Strait, Cal.; reconnaissance and main triangulation across the Sacramento Valley, including the selection of the Yolo base-line; triangulation and topography of coast between Bodega Head and Fort Ross, Cal.; erection of a permanent signal on Mount Shasta, Cal.; topography and triangulation of the coast of Oregon, above and below the Nehalem River, and continuation of hydrography of the Columbia River; tidal observations at Astoria, Oreg.; hydrography of Admiralty Inlet, W. T., from Duwamish Bay to Port Madison; tidal observations at Port Townshend, W. T., and at Honolulu, Sandwich Islands.

In the office the work has been kept up to the field-work of the preceding season, the computations of the current, geodetic, trigonometrical, and tidal observations having been duly made, including the preparation of records and results for publication; tide-tables for the principal seaports of the United States for the year 1877 have been published; the drawing of seventy-seven charts has been in progress, and of this number twenty-nine have been completed. Twelve new copper-plate charts have been begun, one hundred and two have received additions by engraving, and twenty-three have been finished; an aggregate of twelve thousand copies of charts has been issued in the course of the year; and a distribution made of upwards of a thousand copies of the annual reports for previous years.

The preparation for publication of the second volume of the Atlantic Coast Pilot (extending from Boston Harbor to New York entrance and including the Hudson River) has been continued and will soon be completed.

ESTIMATES.

The estimates for continuing the survey of the Atlantic and Gulf coast of the United States are intended to provide for the following progress:

FIELD-WORK.—To continue the topography of the western shore and islands of Passamaquoddy Bay and its estuaries; of the coast eastward of Penobscot Bay toward Narraguagus Bay; and of the shores of the Penobscot near Bangor; for the determination of heights at some of the principal trigonometrical points between Boston and the Saint Croix, and of coefficients of refraction; to complete the hydrography of Penobscot Bay and River, and continue soundings in the coast-approaches eastward of Penobscot Bay; to continue a topographical and hydrographic survey of Portsmouth Harbor; to make such additional triangulation as may be requisite for that and other surveys on the eastern coast, and determine the position of new light-houses between Eastport, Me., and New York; to continue soundings along the coast of Maine, and other offshore hydrography between Cape Cod and Manan, and make special examination for the sailing-lines for charts; to continue the observations of sea and tidal currents in the Gulf of Maine; to continue tidal observations and to make such astronomical and magnetic observations as may be required; to continue such topographical and hydrographic resurveys of the coast between Cape Cod and New York as may be found necessary; to continue the survey of the Connecticut River from its mouth to Hartford; to make such examination as may be required in New York Harbor and such surveys in its vicinity as may be found necessary, including a topographical and hydrographic survey of the south coast of Long Island; to make at this port observations on tides and currents; to extend the plane-table survey of the Hudson River above Haverstraw; to continue the triangulation between the Hudson River and Lake Champlain; to make the requisite astronomical observations; to continue the topographical and hydrographic surveys of the coast of New Jersey, and of Delaware Bay and River; to connect the Atlantic triangulation with that of Chesapeake Bay, near the boundary-line between Maryland and Virginia; to complete the detailed survey of James River, Va., including the hydrography; and continue the plane-table survey of the Potomac River; to continue southward the main triangulation along the Blue Ridge, parallel with the coast, including astronomical and magnetic observations; to continue the supplementary hydrography between Cape Henlopen, Del., and Cape Henry, Va., and in Chesapeake Bay; and also the tidal observations; to measure a base-line of verification and determine azimuth for the coast-triangulation south of Cape Lookout; to make the astronomical and magnetic observations requisite; to continue the off-shore hydrography between Cape Henry and Cape Fear; to continue the hydrography of Pamplico Sound and its rivers, and that of Bogue Sound, and sound the entrance to Cape Fear River; to extend northward the primary triangulation along the eastern and southern slopes of the Alleghanies in North Carolina and Alabama; to continue the topographical and hydrographic survey of rivers near the coast of South Carolina and Georgia; to determine azimuth for the triangulation of the coast of South Carolina and Georgia; to continue the detailed survey of the sea-islands and water-passages between Charleston and Savannah, and to make tidal observations; to continue the off-shore hydrography between Cape Fear, N. C., and the Saint John's River, Fla.; to continue southward from Cape Canaveral the triangulation, topography, and hydrography of the eastern coast of Florida, including Indian River; to continue the triangulation, topography, and hydrography of the Saint John's River; to make the requisite astronomical observations; to continue hydrography off the eastern coast of Florida, from Mosquito Inlet to the southward; to continue soundings and observations for sea-temperatures in such parts of the Gulf Stream as may be deemed advisable, between the west end of Cuba and Nova Scotia, and dredging along the coast within the same limits, in conjunction with the United States Commission on Fish and Fisheries; to continue the astronomical and magnetic observations requisite between Cape Florida and Pensacola; to complete the triangulation, topography, and hydrography of the western coast of Florida between Cedar Keys and Tampa Bay; to continue the same classes of work to the southward of Charlotte Harbor; and to complete the coast between Appalachee Bay and Pensacola; to run lines of soundings and make observations of sea-temperatures in the Gulf of Mexico, and develop the hydrography of the Gulf Coast included in field-operations; to connect the trigonometrical survey of the Mississippi River at New Orleans with that of Lake Borgne and Lake Pontchartrain, and continue the trigonometrical, topographical, and

hydrographic survey of Lakes Pontchartrain and Maurepas, and of the Mississippi River above New Orleans to the head of ship-navigation; to determine geographical positions, and make the astronomical and magnetic observations requisite; to extend the triangulation, topography, and hydrography of Louisiana westward of the Mississippi delta, and continue the hydrography of the Gulf of Mexico between the mouth of the Mississippi and Galveston, Tex.; to continue the triangulation, topography, and hydrography of the coast of Texas westward between Sabine Pass and Galveston, and between Corpus Christi and the Rio Grande; to measure a base-line of verification, and make the astronomical and magnetic observations requisite between Sabine Pass and the Rio Grande; to continue the hydrography of the approaches to the coast of Texas; to continue the determination of the positions of new light-houses and life-saving stations along the coast between New York and the Rio Grande; to continue the field-work for the description and verification of the work for the Coast Pilot; to continue the organized system of magnetic observations required for a complete magnetic survey, and to run lines of levels connecting points in the main and geodetic triangulations with the sea-level.

OFFICE-WORK.—To compute results from the field-operations made along the Atlantic and Gulf coasts, including astronomical, geodetic, geographical, magnetic, and tidal work; to continue the reproduction of the original topographical maps, and to plot the hydrographic charts; to continue the drawing of the general chart of the coast from Quoddy Head to Cape Cod, and of charts Nos. 1 and 2, showing the coast of Maine, between Saint Croix River and Petit Manan light-house; to continue the drawing and engraving of chart No. 3, which includes Frenchman's Bay, Mount Desert Island, Blue Hill Bay, Isle au Haut Bay, and their approaches, also local charts of Mount Desert Island, Union River, Eggemoggin Reach, Deer Isle, Head Harbor on Isle au Haut, and Penobscot River from Castine to Bangor; to complete the engraving of the chart of Lake Champlain; to continue the drawing and engraving of charts of Thames River, and of Connecticut River, to the head of navigation; to continue a new chart of Long Island Sound; to continue the drawing and engraving of charts No. 22 and No. 23 between Barnegat and Cape May; to make additions to the charts and sketches between New York and Cape Henry; to continue the drawing and engraving of a new chart of Delaware Bay and River, and to complete that of James River; to complete the engraving of charts No. 42, No. 43, No. 44, including Pamplico Sound; and continue that of No. 45, No. 46, and No. 47, showing parts of the Atlantic coast between Cape Hatteras and Cape Lookout; and to continue the drawing and engraving of charts No. 51 and No. 52, between Cape Fear and Winyah Bay; to continue the drawing and engraving of a new chart of Georgetown Harbor, S. C., and to make additions to the charts between Cape Henry and the Saint Mary's River; to continue the drawing and engraving of the general chart of the coast from Saint Mary's River to Cape Canaveral, and of charts No. 59, No. 60, and No. 61 from Saint Augustine to Cape Canaveral, and to make additions to the charts of the coast between Saint Mary's River and Cape Florida; to continue the drawing and engraving of chart No. 77, Tampa Bay, and of No. 84, No. 85, No. 86, and No. 87, showing the Gulf coast between Cape Saint Blas and Mobile entrance; to complete the drawing and engraving of charts No. 92 and No. 93, showing Isle au Breton Sound and the Passes of the Mississippi, and the general charts showing the sea-approaches to the Mississippi River; to continue the drawing and engraving of the general chart of the coast of Louisiana and Texas, from Atchafalaya Bay to Galveston; to continue the drawing and engraving of that between Galveston and the Rio Grande, and of chart No. 110, showing Corpus Christi Bay; for material for drawing, engraving, map-printing, for electrotyping and photographing, for instruments and apparatus.

Total for the Atlantic and Gulf coasts, involving work on the coasts of the following States, viz: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas, will require $440,000.

The estimates for continuing the survey of the Pacific coast of the United States are intended to provide for the following progress:

FIELD-WORK.—To make the requisite observations for latitude, longitude, azimuth, and the magnetic elements at stations along the Pacific coast of the United States; to continue offshore soundings along the coast of California, Oregon, and Washington Territory, and tidal observations

at San Francisco, Port Townshend, and such other localities as may be necessary; to continue the main coast triangulation from Monterey Bay to the southward, or from Point Concepcion to the northward, and from San Pedro toward San Diego, including the islands off that part of the coast; to continue reconnaissance for the main triangulation of the coast from San Pedro to Point Concepcion, from Russian River to the northward, from Columbia River north to Puget Sound, or south up the Willamette Valley; to complete the reconnaissance and continue the primary triangulation through the Sacramento and San Joaquin Valleys, and measure a base-line; to continue the coast triangulation and topography from Newport, Los Angeles County, toward San Diego, and that of the islands off that coast; to continue the tertiary triangulation and topography of the coast north of Point Concepcion toward Point Sal, or the tertiary triangulation and topography from Point Buchon toward San Simeon; to continue the hydrography between San Diego and Monterey Bay; to develop the hydrographic changes in San Francisco Bay and its approaches; continue the triangulation and topography of the coast between Bodega Bay and Point Arena; complete hydrography between Cape Mendocino and the Klamath River; and continue that between Cape Sebastian and Port Orford, with that north and south of and in the approaches to the Columbia River; to observe currents along the coast, and take soundings and temperature-observations in the California branch of the Kuro-Siwo Current, and execute such other hydrographic work as local demands may require; to continue tidal and current observations at the Golden Gate, and observations on the ocean-currents along the coast of California; to continue the triangulation, topography, and hydrography of the Columbia River; to complete the detailed survey between Cape Sebastian and Crescent City, and offshore hydrography at Crescent City Reef; to measure a base-line and continue the triangulation of the Strait of Fuca and the topography and hydrography of Puget Sound and adjacent waters; to continue the reconnaissance of the coasts and islands of Alaska, with observations for tides and currents, and to make the requisite astronomical and magnetic observations; to continue the field-work for the description of the coast and verification of the Coast Pilot of the coasts of California, Oregon, and Washington Territory; to continue the organized system of magnetic observations required for a complete magnetic survey; and to run lines of levels connecting points in the main and geodetic triangulations with the sea-level.

OFFICE-WORK.—To make the computation from the observations made in the field, including astronomical, geodetic, geographical, magnetic, and tidal observations; to continue the reproduction of the original topographical maps, and to plot the hydrographic charts; to draw and engrave the additions on the general chart of the Pacific coast of the United States; to continue the drawing and engraving of the charts of the coast from San Diego to Point Concepcion, No. 1 and No. 2; to continue the engraving of a new chart of San Francisco Bay and Harbor, in three sheets, from resurveys; to continue the drawing and engraving of charts of the coast No. 6 and No. 7 from the Farallones to Cape Mendocino, of No. 8 from Cape Mendocino to Saint George's Reef, of No. 9 from Saint George's Reef to Koos Bay, and of No. 11 from Cascade Head to Shoalwater Bay; to continue the drawing and engraving of the chart of Columbia River and of the local harbor charts of the coast, with those of Puget and Washington Sounds, and of the northwestern coast; for material for drawing, engraving, map-printing, for electrotyping, photographing, for instruments and apparatus.

Total for the Pacific coast, involving work on the coasts of the States of California and Oregon, and those of Washington Territory and Alaska, will require $245,000.

For extending the triangulation of the Coast Survey to form a geodetic connection between the system of triangulation along the Atlantic and Gulf and Pacific coasts of the United States, and assisting in the State surveys, involving work in New Hampshire, Vermont, Connecticut, New York, Pennsylvania, New Jersey, Virginia, West Virginia, North Carolina, Tennessee, Alabama, Missouri, Illinois, Wisconsin, Kentucky, Kansas, California, Nevada, and Utah Territory, will require $90,000.

For repairs and maintenance of the complement of vessels used in the Coast Survey will require $55,000.

For continuing the publication of the observations made in the progress of the Coast Survey will require $10,000.

For general expenses of all the work, rent, fuel; for transportation of instruments, maps, and charts; miscellaneous office-expenses, and for the purchase of new instruments, books, maps, and charts, will require $40,000.

PENDULUM-OBSERVATIONS.

By the measurements of arcs of the meridian, the approximate figure and magnitude of the earth was ascertained at an early period in the history of geodetic surveys. This was matter of necessity, as any extended survey, in respect of final precision, would depend on knowledge of the terrestrial outlines. In confirmation of the result from ordinary geodetic processes, the average figure of the earth, though not its magnitude, has been inferred also from observations of gravity in various latitudes by means of the pendulum. This was the first method employed, and the one preferred by Newton. The several results so derived have been long on record, and although imperfect, as were the instruments and methods used in a former day, the results are in such general accord as to warrant the application of refinements in apparatus and improvement in the methods of observation that had not been reached in the time of Borda and Biot. Natural difficulties that beset the early observers of course yet interfere.

In the measurement of arc local deflections of the plumb-line affect the astronomical amplitudes, and the pendulum reveals deviations in the force of gravity due to inequality of density in the earth's strata. Hence it is, notwithstanding the great precision with which latitudes and longitudes are determined, and the force of gravity ascertained at any one point, that very sensible residuals or apparent errors are found when we attempt to refer these results to any geometrical form. The cause of these discrepancies or "station errors" being beyond reach we can only endeavor to infer from all attainable sources what, under the denomination of figure of the earth, will best reconcile determinations of geographical position. The measure of the force of gravity, commonly denoted by the letter g, independently of what application is to be made of it, is universally recognized as one of the results due in a geodetic survey.

Within the last sixty years the solution of the problem respecting the measure of the force of gravity and figure of the earth as deduced from such measures has been aided by the experimental researches of Kater, Sabine, Plantamour, and others. Fresh stimulus in the inquiry was manifest in 1862, when the Geodetic Association of Europe, after due examination, recognized the pendulum as an instrument of great precision, and approved of its use in geodetic surveys. Since that year it has been employed in the great trigonometrical survey of India, and in 1865 and 1873 the pendulums used in India and in the Russian survey were swung at Kew Observatory, England, so that the results obtained at widely-separated positions on the surface of the earth are now comparable. They are also to be swung in Berlin.

With a view of providing for a comparison of the pendulum-observations of the Coast Survey with European and Asiatic systems which have been further advanced practically, Assistant Chas. S. Peirce was directed early in the spring of 1875 to procure apparatus of the invariable and reversible pendulum, and to observe with them at Paris, Geneva, Berlin, and Kew. His inquiries on the subject in Europe include also the details of the most approved forms of apparatus and the best methods in use for the improvement of the pendulum as an instrument for geodetic purposes. Theoretically and practically the study is such as to require extreme care and special attention in regard to the efficiency of the vacuum-chamber, the elasticity of the support, the loss of energy by propagated vibrations in the stand, the real temperature of the pendulum-bar, and many other conditions. There are several important forms, including that proposed by Bessel, but the two forms of apparatus specially referred to in this notice may be defined as follows: The invariable pendulum is a plain bar having near one of its ends a knife-edge by which it is suspended. This form is usually employed as a differential instrument, and for general use it therefore requires to be swung at a station where the force of gravity has been ascertained. But the reversible pendulum carries a knife-edge near each of its ends, and it may be swung from either. By means of movable weights (the use of which has been generally abandoned) the reversible pendulum can be so adjusted that when swung by either knife-edge the center of oscillation will coincide with the opposite knife-edge. The distance between

the knife-edges is then precisely equal to the length of the mathematical or simple pendulum oscillating in the same time. A chief advantage of the reversible pendulum is that it eliminates the effect of buoyancy and resistance of the air. The axes of suspension being interchangeable, this instrument is known also as the convertible pendulum. If it oscillates in a second of mean time it is known as the seconds pendulum, and the force of gravity at the place may be deduced from accurate measurements of its length. If, as usual, its oscillations do not exactly coincide with mean time, a small correction is applied to its measured length to give the true length answering to coincidence, and for that purpose a measure of the position of its center of gravity is requisite. The length of the reversible pendulum is one meter.

In the Appendix (No. 15), a paper by Assistant Peirce is given descriptive of his pendulum-observations at European stations, and also a scheme for a history and discussion of the pendulum and its relations to gravitation.

Assistant Peirce sailed from New York on the 3d of April, 1875. He proceeded at once to England, where he ascertained that the Kew Observatory is regarded as the initial point for British pendulum-work. This observatory, which is situated in the old deer-park at Richmond, is the property of the Crown, but the operations conducted there, which are chiefly of a magnetical and meteorological description, have been kept up by the Royal Society, through a special committee, and also by the Royal Meteorological Office. R. H. Scott, esq., who directs the Meteorological Bureau, is also chairman of the Kew committee. The pendulums of the Great Survey of India were swung at this observatory, both before and after the operations in India, the observatory being occupied at first by Captain Basseri during a year for this purpose, and afterward by Captain Heavyside during a year and a half. It is believed that the pendulums of Major-General Sir Edward Sabine were also oscillated here; in any case, all the historical English pendulums are here collected, and can be swung at any time if necessary. By the action of the American minister, General Schenck, an application was made, through the British Foreign Office, for permission to experiment with the American apparatus at the Kew Observatory, and to this request a favorable response was eventually received. Late in May, 1875, Assistant Peirce proceeded to Germany, where a Bessel's convertible pendulum, having the length of one meter between the knife-edges and being a copy of the instrument used in the Prussian survey, had already been ordered of the Messrs. Repsold. It may be mentioned that the convertible pendulum, which was invented by Bohnenberger, had been first seriously employed by Kater. Bessel, however, described such an improvement as to effect the complete elimination of all effect of atmospheric resistance and friction. Long after Bessel's death this improved instrument was constructed by Repsold, and was adopted by the Swiss survey and first used by Professor Plantamour, who developed the method of employing it. It is now exclusively used on the continent of Europe, and has received the unanimous sanction of the International Geodetical Association. An instrument of this sort had been ordered by the Coast Survey at the commencement of the pendulum-operations in 1872, but owing to the Messrs. Repsold being then occupied with preparations for the transit of Venus, the apparatus was not completed until the spring of 1875. This is not the place for any description of this instrument, which was executed with the consummate art and precision for which this celebrated firm of mechanicians is distinguished. This instrument having been procured, Assistant Peirce readily obtained from Professor Förster, the eminent director of the Berlin Observatory and president of the Imperial German Commission of Weights and Measures, the permission to make all necessary experiments in the building of the Office of Weights and Measures in Berlin, upon the very spot where the determination of Bessel had been made. This building has been erected expressly for the purpose of making accurate comparisons of standards of length. It is built with very thick walls of hollow brick, and the comparison chambers are lined with systems of flues, through which, by means of an engine in an adjoining building, hot air can be conveyed from a furnace or cold air from an ice-house. This building, which will serve as a model for similar buildings in other countries (as it already has in France), is the most suitable possible place for pendulum-experiments. The building, however, was not sufficiently completed in the summer of 1875 to allow of pendulum-experiments being made there to the greatest advantage. It was thought desirable to make a careful comparison of the

American reversible pendulum with that of Prussia. The celebrated geodesist, Lieutenant-General Dr. Baeyer, the director of the Royal Prussian Survey, who furthered Assistant Peirce's operations in the most gratifying manner throughout his stay upon the continent, at once placed the Prussian instrument at his disposal, and the meter-scale of this apparatus, which had already been carefully compared with the Prussian normal meter at different temperatures by Professor Förster, was submitted to fifty independent series of comparisons with the similar scale of the American standard by Assistant Peirce. These operations, which yielded a very satisfactory result, lasted until July 7. Assistant Peirce afterward proceeded to Geneva, where, upon the return of Professor Plantamour (who was at first absent), arrangements were readily made for oscillating the reversible pendulum at the observatory of this city. Assistant Peirce had thus, at the outset of his operations with Bessel's pendulum, the signal advantage of receiving the counsels of the distinguished *savant* who first introduced the use of it, and who has studied so carefully the methods of its manipulation. Actual experiments were made upon seventeen days, between August 26 and September 17. The method of making the experiments, adopted by Assistant Peirce, may here be described. It has been slightly modified from time to time, but its latest form is as follows: On the first day, the rigidity of the stand and the position of the center of gravity of the pendulum are measured. The next day is devoted to comparisons of the pendulum and standard. The oscillations are then commenced; and no measures of the pendulum are made upon days devoted to these experiments. During the swingings of the pendulum the Repsolds "firma" is always forward. Each day the pendulum is first swung with the heavy end up, then with the heavy end down, and then with the heavy end up again. Two such sets of experiments are sometimes made in one day, but this is considered rather objectionable. After four such sets, the pendulum is remeasured the next day. A day is then devoted to remeasuring the frame of the stand, to interchanging the knife-edges, and to determining the center of gravity before and after this change. In interchanging the knife-edges, they are never reversed end for end. A day is then given to measuring the pendulum. Four more sets of swingings are then made. The pendulum is then again measured as before, and then the determinations of center of gravity and flexure are repeated. Fifteen days might be occupied by such a determination, but in practice it is necessary to vary the proceeding more or less. The times of oscillation are determined by observing transits of the pendulum across the web of a telescope and registering the time upon a chronograph. One hundred transits are observed each time, and in one of the following orders:

A. 25 transits from right to left, then 50 from left to right, then 25 from right to left.
B. 50 transits from left to right, then 50 from right to left.
C. 50 transits from right to left, then 50 from left to right.
D. 25 transits from left to right, then 50 from right to left, then 25 from left to right.

Choice is made between these methods, so that the signals will not interfere with the two-second breaks of the chronometer, which affect the same pen. Four sets of transits are so taken that at their mean times respectively the oscillations of the pendulum have the half-amplitudes 2°, 1½°, 1°, and ½°. Different eye-pieces are used with magnifying powers nearly inversely proportional to the amplitudes, so that the apparent velocity shall remain constant.

The observatory of Geneva is a small building with one main room, opening by large glass doors to the north and south. The floor is of asphalt, and the instrument rested upon the floor. There was necessarily more or less walking about, and several visitors each day entered at the glass doors just mentioned. Assistant Peirce received every possible assistance and attention from Professor Plantamour and his assistants, but it is necessary to note the fact that the place was hardly suitable for such operations. Observations of time were made by the assistants of the observatory.

At Geneva, Assistant Peirce set up a micrometer in front of the pendulum-stand, and by means of a weight passing over a pulley, whose friction was determined, he measured the flexure of the support of the pendulum, and determined the important correction, amounting to over $0^{mm}.2$, to be applied to the length of the seconds pendulum on account of the swinging of the stand from side to side as the pendulum swings.

Proceeding to Paris, Assistant Peirce had the honor and advantage of attending the sittings of

the International Geodetical Association and of its standing committee, which met in September, 1875, in the palace of the Ministry of Foreign Affairs. The whole subject of the pendulum received a thorough discussion, and a resolution was unanimously passed expressing the sympathy and interest of the association in the expedition of Assistant Peirce. The reversible pendulum had unfortunately sustained grievous damage in transportation from Paris to Geneva. Thus one of the great advantages of this instrument received illustration; for if it had been an invariable pendulum, the connection between previous and subsequent operations would have been entirely destroyed; whereas, with the existing construction, the pendulum had only to be put again in condition in order to give results perfectly comparable with those which had gone before. During the interval created by this accident the Geneva observations were completely reduced.

Permission was granted by his excellency M. Wallon, Minister of Public Instruction, Worship, and the Fine Arts, for oscillating the American pendulum at the observatory at Paris. M. Leverrier afforded every assistance; and the operations were conducted in the great Salle du Meridien, where the pendulums of Borda, of Sabine, and others had previously been swung. The experiments were conducted in the recess at the northern end of this hall, and were made upon eighteen days, between January 18 and February 29, 1876. The standard clock of the observatory was made use of, and its corrections were furnished by the observatory. M. Wolf, the well-known astronomer attached to the observatory, to whom the arrangements for the experiments were intrusted by the illustrious director, rendered Assistant Peirce in the most gracious manner all the aid that this magnificent institution could furnish.

On the conclusion of the experiments in Paris, Assistant Peirce again repaired to Berlin, and as soon as the great comparing chamber of the Bureau of Weights and Measures was ready, experiments were commenced there upon a pier at the northern end. As before, every possible assistance was received from Professor Förster and Lieutenant-General Baeyer. The experiments were made upon twenty-four days, from April 19 to June 6, 1876. A clock was furnished by the observatory, which was compared with the normal clock whose corrections were furnished by the observatory.

A standard meter with lines and also cylinders for comparison with an end measure was, at a subsequent visit, furnished to Assistant Peirce by the Imperial Commission of Weights and Measures.

After the experiments in Berlin, a favorable response having been received to the application of Assistant Peirce for permission to make his experiments at the Kew Observatory, he went to England and commenced experiments without delay. The observations commenced in June, and were finished in July. The time was observed by Mr. Henry Farquhar, with the transit of the observatory, and four chronometers were kept running at once.

Mr. Peirce arrived at Boston August 26, 1876. He is at present occupied in completing the connection of the determinations of gravity in Europe and America.

MAGNETISM.

In the operations of the survey from year to year, determinations have been made of the variation of the compass or magnetic declination, and also of the dip of the needle and the magnetic intensity. Part of these observations were merely incidental to the prosecution of other branches of the work, but in that way much information has been gathered, and this from time to time has been combined with data from other sources for the means of marking our coast charts with the variation of the compass. To this prime necessity in the interest of navigation have been added in later years increasing inquiries in regard to the bearing of lines in land-surveys of old date. Numerous inquiries of this kind have been answered at the office, but thus far the means for precision have been limited by the scarcity of observations in the interior. In the course of the coming year it is proposed to select and occupy such points as will most effectually combine with those at which the variation of the compass has been already determined and thus to gain, as early as possible, the means of tracing lines for equal magnetic declination from the interior across the coast and with assured accuracy to continue them out to sea. On sketch No. 2 all the magnetic stations occupied by Coast Survey observers between 1833 and 1877 are marked. At all of these the declination, and at most of them the magnetic dip and intensity have been determined. Several of the stations have

been reoccupied for the study of the secular change, and these are indicated in the sketch by a larger dot. In my next annual report such stations as it may be practicable to occupy in the interior during the fiscal year '77–'78 will be indicated in a similar sketch.

LONGITUDE.

The first notice published by the Coast Survey in regard to the use of the electric telegraph for geodetic purposes appears in the Coast Survey Report for 1846, in which the method devised by officers of the Coast Survey for determining differences of longitude is fully described and where the first results are given.

These gave difference in time to the tenth of a second between the Naval Observatory at Washington and the High School Observatory at Philadelphia. In the course of a few years all the details requisite for the utmost precision were completed in this office, and all was in readiness when the opportunity was afforded for determining by that method the difference in longitude between points in America and Europe.

At this day this method enjoys extreme favor on account of its simplicity in theory and the great accuracy in its results, in Europe as well as in America, as shown by its wide-spread application.

On sketch No. 3 all stations of which the longitudes have been determined by the survey through the means of the electric telegraph between the year 1846 and the end of the present year are marked The connection by telegraph between the stations is indicated by broken lines.

PART II.

The abstracts which follow under separate heads are arranged in geographical order, beginning with mention of work done on the coast of Maine, and closing with notices of work on the coast of Texas. For the Pacific coast, the abstracts will mention first the operations near San Diego, and proceeding northward, will close with a description of the operations in Washington Territory. Appendix No. 1 shows, in tabular form, the distribution of surveying parties in the course of the fiscal year ending June 30, 1876, and sketch No. 1 exhibits in a general way the progress so far made in the main branches of the survey. In the concluding chapter of the report will be found a brief statement of the work of the year in the office, of which the details have been conducted as heretofore by Assistant J. E. Hilgard.

The hydrographic inspector of the Coast Survey, Commander Edward P. Lull, U. S. N., has earnestly co-operated in the arrangements needful for such of the parties as require vessels. Within the year three steamers, three schooners, a small steam-cutter, and two steam-launches have been completed and equipped in accordance with plans devised to insure their efficiency in the service for which each of the vessels was designed. Of the old vessels entirely worn out in the service, seven have been sold within the year.

Lieut. H. E. Nichols, U. S. N., remained on duty until the 17th of December. After performing the special service for which he was then detached, Lieutenant Nichols was reassigned to the Hydrographic Division on the 16th of June. All the original hydrographic sheets are carefully examined in this Division in advance of being registered and deposited in the archives.

SECTION I.

ATLANTIC COAST OF MAINE, NEW HAMPSHIRE, MASSACHUSETTS, AND RHODE ISLAND, INCLUDING SEAPORTS, BAYS, AND RIVERS.—(SKETCHES NOS. 4 AND 5.)

Hydrography, Gulf of Maine.—The party in charge of Lieut. Commander C. D. Sigsbee, U. S. N., assistant in the Coast Survey, with the steamer Blake, was in effective condition on the coast of Maine in July, 1875, and resumed hydrographic work late in that month on Cashe's Ledge. Special attention was first given to the development of the vicinity of Ammen's Rock on this ledge, determined by Lieut. C. H. Davis, U. S. N., assistant in the Coast Survey in 1848, and having as little as twenty-six feet of water. Another rock was found by Lieutenant-Commander Sigsbee, and its carefully determined position proved to be about four miles southwest of the place assigned to Ammen's Rock. The depth at mean low water on the rock last found is five fathoms. Current-observations were recorded while the party was engaged in this work, which was prosecuted with frequent interruptions, the weather being generally either foggy or stormy. Early in September, and after riding out a severe gale of several days, the steamer returned to Portland, sounding at intervals on the line between that port and Cashe's Ledge. Later in the month Lieutenant-Commander Sigsbee repeated soundings on the same line, passed around the ledge, and continued soundings toward Matinicus Rock. From thence it was intended to extend the deep-sea work by a line across George's Bank, but the weather proved too stormy for continuing below Jeffrey's Bank. Soundings were repeated on this line on the return to Matinicus. During a severe gale which followed, the steamer remained in Rockland Harbor, but operations were resumed near Matinicus on the 20th of September. A line of soundings was extended southward and westward, and then southward and eastward to a position on the line which had been previously carried south of Matinicus, and thence onward soundings were recorded to the southward of George's Bank, a depth of 1,171 fathoms being found where the work was discontinued. There a line was commenced and continued to Head Harbor light-house, and from the end of this latter line soundings were carried to Cape Cod.

Lieutenant-Commander Sigsbee reports that in crossing George's Bank, some of the soundings gave as little as 10 fathoms of water.

Intending to complete the hydrographic survey of the vicinity of Cashe's Ledge, the steamer was employed early in October in sounding on a course between the ledge and Provincetown, to

which harbor the vessel had been forced for shelter from a heavy gale. But on the night of the 3d the wind and sea having increased so as to make further soundings impracticable near the ledge, the course was changed and a deep-sea line was extended toward Cape Porpoise. The heavy weather which had prevailed almost continuously having constrained the postponement of further operations in hydrography, Lieutenant-Commander Sigsbee proceeded with the steamer to Portland and made arrangements for completing the office-work resulting from the service performed afloat. Surface currents were observed generally at all the positions at which depths were determined. The devices perfected by Lieutenant-Commander Sigsbee for sounding at sea with wire have been applied with uniform success both in this section and in the Gulf of Mexico. His operations in the last mentioned quarter will be described under Section VIII in this report.

The statistics of work done by the party in the steamer Blake on the coast of Maine, include records of temperature at the sea bottom, at the surface of the water, and at intermediate depths, and records of the density corresponding to each of the temperatures thus ascertained. Specimens of the water and of the bottom were sealed for future reference or investigation.

The general hydrographic statistics are:

Miles run in sounding	2,065
Number of soundings	664
Currents observed (stations)	65

Lieutenant-Commander Sigsbee was assisted in the hydrographic operations here noticed by Lieut. J. E. Pillsbury and W. O. Sharrer, by Masters R. G. Peck and M. F. Wright, and by Ensign W. E. Sewell, U. S. N.

Triangulation and topography of Placentia Bay, Me.—In continuation of the plane-table survey of the coast of Maine, in the vicinity of Mount Desert Island, Assistant J. W. Donn proceeded to this section in July with his party in the schooner Scoresby. In order to provide points for topographical work, several stations were first occupied with the theodolite on Swan Island, and horizontal angles were measured to determine by triangulation the relative positions of Pond Island, Black Island, Long Island, and others in that immediate neighborhood. These were all surveyed carefully with the plane-table in August and September, and that work completes the detailed topography of the islands of Maine as far eastward as Mount Desert. Fogs prevailed early in August, but the latter part of the season was more than usually favorable for progress. The statistics of the work are:

Stations occupied	8
Angles measured	135
Shore-line surveyed, miles	109
Roads, miles	13
Streams, miles	21
Area of topography, square miles	23

Sixty-eight islands, large and small, are represented on the plane-table sheet and the outlines of thirteen ponds. Earlier in the season the party of Assistant Donn was employed in Section II and subsequently in Section III. Messrs. F. C. Donn and F. H. Parsons served as aids in the plane-table party.

Topography of Blue Hill Bay, Me.—In previous seasons the plane-table survey had been advanced eastward by Assistant W. H. Dennis to the vicinity of Blue Hill Bay. Field-work was resumed by a party under his charge in the middle of July, 1875, and was continued until the 20th of October. The ground mapped by the party includes a breadth of about two miles along the western shore of Blue Hill Bay, and extending northward nearly ten miles or beyond the village known as Blue Hill.

An extensive salt-pond and several post-towns are among the details represented on the topographical sheet. The roads following the course of the shore-line were traced as in all like cases, as were also the outlines of such rocks and ledges as were found bare at low water. Mr. Dennis was aided in this section by Subassistant H. W. Bache and Mr. S. N. Ogden. Reference

will be made under Section V to the subsequent operations of the party. The statistics of work done on the shore of Blue Hill Bay are:

Shore-line surveyed, miles	42
Roads, miles	43
Area of details, square miles	20

Assistant Dennis found the weather more than commonly favorable in this section.

Hydrography of Isle au Haut Bay, Me.—Lieut. J. M. Hawley, U. S. N., assistant in the Coast Survey, sailed from Boston on the 12th of July, 1875, with his party, in the schooner G. M. Bache. On reaching Portland the steam-launch Sagadahoc was repaired for service in the hydrography, and the two vessels arrived at their site of work in the eastern part of Isle au Haut Bay before the close of the month. Stations of the triangulation were soon identified, and signals for the work were set up without delay. Frequent fogs and gales interrupted the progress of the party, but soundings were recorded at all favorable intervals until the 20th of October. The hydrographic sheet resulting from the work represents the water space and depths to the westward of Deer Isle and between it and the western ends of Bradbury and Pickering Island, and as far to southward as Mark Island. As usual, the rocks and ledges within working limits were carefully developed. Tidal observations were recorded at two stations for an entire lunation, and at several temporary stations as the work advanced. In reference to the currents near Northwest Harbor and Green's Landing, Lieutenant Hawley remarks: "Although the rise and fall of the tide at these places was considerable there seemed to be but little tidal current, vessels invariably swinging to the wind. In sounding, the currents experienced were few, and those very slight."

The bottom as developed by the soundings is very irregular, and where rocky is covered with kelp. In the harbor of Deer Isle the bottom is soft mud, and affords excellent anchorage. After closing work for the season the steam-launch was laid up at Burnt Cove. The schooner was taken to Baltimore and refitted for service on the southern coast. A synopsis of the statistics of hydrographic work is thus given in the report of Lieutenant Hawley:

Miles run in soundings	270
Angles measured	1, 824
Number of soundings	19, 771

During the winter and spring of the present fiscal year this party was employed on the Gulf coast, as will be mentioned under the head of Section VI. On the coast of Maine, Lieutenant Hawley was assisted by Master G. L. Hanus and Ensign J. M. Wight, U. S. N.

Topography of Bagaduce River.—For the completion of this work Assistant Hull Adams resumed operations early in July, 1875, at the limit of his survey of the preceding season. After mapping the surface details in the vicinity of Northern Bay and the reefs and islands adjacent, a second plane table sheet was completed, showing the head of Bagaduce River, Walker's Pond, Herrick's Bay-South Bay, the contour of intervening ground, and the roads that traverse that quarter. Among the features represented are the villages of Brooksville and West Brooksville and granite quarries in the neighborhood. The detailed survey was completed on the 15th of October. Mr. W. E. McClintock served as aid in the field. In statistics the results are:

Shore-line traced, miles	32
Roads, miles	50
Streams, miles	51
Area of topography, square miles	28

The plane-table sheet last referred to essentially completes the topography of the coast between the Penobscot and Blue Hill Bay.

Topography of Penobscot River, Me.—The survey of the shores of the Penobscot was resumed in the middle of July, 1875, by Assistant A. W. Longfellow at limits near Bucksport and Winterport, which had been reached in the work of previous seasons. On the west bank the detailed topographical survey was extended upwards to Crosby's Narrows, above the Sowndabscook Branch, which enters the river about a mile above Hampden Upper Corner. The work on the east bank was carried to a corresponding limit in the town of Orrington. On both sides of the Penobscot, a mar-

gin averaging rather more than a mile was mapped in detail, giving a considerable aggregate of contour at the towns of Winterport and Hampden, and also along the east side of the river. The character of the topography is diversified; but the prominent features on the plane-table sheet show arable and wood land along the valley of the Penobscot and the roads, farms, and surface characteristics generally. The survey was continued until the 4th of November, but with many interruptions of bad weather during the latter part of the season. Assistant Longfellow was aided by Mr. W. C. Hodgkins. The statistics of work are:

Shore-line surveyed, miles	25
Streams, miles	56
Roads, miles	43
Area of topography, square miles	18

Tidal observations.—At North Haven, on one of the Fox Islands in Penobscot Bay, an excellent series of tidal and meteorological observations begun in 1870 has been continued through the fiscal year by Mr. J. G. Spaulding. The self-regulating gauge there in use is one of the best, and being provided with means for circulating hot water through the float-box, the register has never been stopped by freezing. When stopped at short intervals occasionally for repairs, the series of observations have been continued by means of a staff-gauge. Every high water and low water from the beginning appears on the record of this station.

Coast Pilot.—The work of compiling and verifying sailing-directions has been continued by Assistant J. S. Bradford with a party in the schooner Palinurus. That vessel sailed from Norfolk on the 13th of July, 1875, and continued work in the vicinity of New York until the 4th of September, when the party was transferred to the coast of Maine, the season being then favorable for taking the views needed for charts. All points of interest about Passamaquoddy Bay were sketched by the draughtsman, Mr. John R. Barker, previous to the middle of September. At Eastport, where the strength of the tide was such as to make it doubtful whether the Palinurus would be of service, Capt. David Evans cordially tendered the use of the revenue marine steamer Levi Woodbury, and with that vessel the work in the vicinity was well and quickly done.

Between September 24 and the 20th of October the party was fully occupied in revising the first edition of the Coast Pilot and making views of the coast between Passamaquoddy and Penobscot Bays. Thirty-seven views of intervening parts of the coast were completed satisfactorily.

Broad Cove Rock in Portland entrance was examined on the way southward, its crest having been reported as bare at extreme low water. Careful soundings by the party in the Palinurus developed nothing less than seven feet at low water. Proceeding direct to Boston Harbor close inspection was made by Assistant Bradford of the harbor improvements and alterations, and corresponding changes were made in the manuscript of the Coast Pilot. At the end of October the vessel left Boston and returned to New York. Work done in the vicinity of the last-named port will be stated under the head of Section II.

On the coast of Maine two views were taken of approaches to Eastport; one showing the Wolves (in the waters of the British provinces); two of Little River, Me.; two of Machias Bay; one of the entrance to Little Kennebec River; one of Englishman's Bay; two of Moose-a-bec Reach; one of the approaches to Head Harbor; two of Narraguagus Bay; two of Petit Manan Island; two of approaches to Frenchman's Bay; one of Mount Desert Eastern Pass; two of approaches to Southwest Harbor; one of Bass Harbor; one of Blue Hill Bay; one of the entrance to Burnt Coat Harbor; two of Isle au Haut; two of Eggemoggin Reach; two of Deer Island Thoroughfare; two showing outlying islands of Penobscot Bay; two of Penobscot entrance; two of Fox Island Thoroughfare; one of Belfast Bay; and one of the Penobscot River entrance.

Lieut. C. A. Bradbury, U. S. N., was attached to the party in the Polinurus, and succeeded to the charge of the vessel in December, as will be referred to under the head of Section II.

Coefficient of refraction.—Valuable series of observations were recorded in July, August, and September, 1874, at Ragged Mountain, near Camden, Me., and of these mention was made in my last annual report. Assistant F. W. Perkins then determined the elevation of six points by running lines

with the spirit-level from tidal bench-marks in the vicinity of Penobscot Bay. Two of these heights were proved by the use of the barometer and by measurements with the vertical circle.

In October, 1875, Assistant Perkins returned to the primary-station point on the summit of Ragged Mountain, and repeated his measurement for height with the spirit-level, extending the line to the tidal bench-mark at Camden. The records of work done by Mr. Perkins at that point of the primary triangulation show the hourly observation of zenith distances as measured upon outlying signals, the heights of which above sea had been previously determined. These measurements were originally made between 5 a. m. and 7 p. m., and another series on only one object during the intervening hours of the night, to give means for investigating the law of variation in atmospheric refraction throughout the twenty-four hours. Series of hourly barometric observations were recorded between 6 a. m. and 6 p. m. at Ragged Mountain, at Mount Desert, and also at White Head light-house. These and the data afforded by the other observations have been subjected to discussion by Assistant C. A. Schott. The results found are given in the Appendix No. 17.

Triangulation in New Hampshire.—On the 1st of June, 1875, Prof. E. T. Quimby, of Dartmouth College, took the field for continuing this work, and devoted some days to reconnaissance, in which signals were set up at new secondary points, and such as had been more or less disturbed by the storms of the preceding winter were adjusted. Stations were added to the scheme at Stowell Hill in Rockingham, Vt.; Hawk's Mountain, in Baltimore, Vt.; Mount Washington, and the mountain named Starr King, in New Hampshire. The attention and labor requisite for clearing the lines of sight were given at the outset of the season in advance of resuming angular measurements at either of the stations. These were commenced at Croydon Mountain early in July, and the horizontal angles centering at that station were completed by the 2d of August. The following extracts from the report of Professor Quimby contain a clear statement of the progress made, and a gratifying reference to the incidental co-operation of Prof. C. A. Young, the able astronomer, also of Dartmouth College:

"Besides the usual observations of direction with the 24-inch theodolite, and measurement of vertical angles with the vertical circle, several evenings were employed in recording astronomical azimuths for which the station on Croydon Mountain afforded some peculiar facilities. By the courtesy and kindness of Professor Young we were enabled to make our station near the observatory in Hanover, an elongation mark, thus gaining advantage in distance, and saving the time of observing an extra point in our day work, On each evening on which azimuth was observed Professor Young sent the true time for determining the error of our chronometer, thus saving us the trouble of observations for that purpose. The professor, moreover, favored us by a personal visit one evening, and by valuable assistance in the series of observations then recorded.

"After the completion of work on Croydon, the camp and instruments were immediately moved and were reset on Bald Ledge, in Monroe, N. H. On account of the long lines to be observed from that station, and the very unfavorable weather, the observations were not completed till September 22, when the instruments were transferred to Observatory Hill for supplementary measurements needful at that station."

A synopsis appended to the field-report gives as statistics of the work:

Signals, &c., observed on	101
Number of observations	2,220
Observations with vertical circle	1,524

Twenty points were determined in geographical position in the course of the season. Professor Quimby took the field again in June of the present year and will prosecute triangulation work during the summer.

Hydrography of the approaches to Saco River, Me.—The supplementary soundings needed for completing a chart of the vicinity above and below Fletcher's Neck were begun on the 12th of October by Assistant F. F. Nes, who had previously in the season worked at two other localities between New York and Boston. Off Old Orchard Beach some of the requisite lines were run, and at intervals previous to the end of the month, the hydrography was filled in near Fletcher's Neck and Whale's

Rock Ledge. Additional work intended was laid aside in consequence of the severe illness which compelled the return of Mr. Nes. The statistics of the work done are as follows:

Miles run in sounding	50
Angles measured	347
Number of soundings	4,328

Tidal observations.—Within the year ending June 30, 1876, some interruptions and several short stoppages occurred in the series of tidal observations at Boston navy-yard, under the charge of Mr. H. Howland. The gauge is one of the old form, and was furnished with heating apparatus, but though not long used at the location, mud had accumulated around the float-box, rendering the action of the float uncertain. In November, the instrument was moved to the wharf on which it had been used formerly. The change proved advantageous, and further means will be taken to preserve the continuity of the series. Meteorological observations have been recorded at that station as heretofore.

Life-saving stations.—The expediency of marking the original topographical sheets of the Coast Survey with the positions of all the life-saving stations having been decided upon in conference with the inspector, Capt. J. H. Merryman, of the United States Revenue Marine, direction was given to that effect. The details of the service were intrusted to Assistant F. H. Gerdes, who proceeded in the middle of July, 1875, to Rockland, Me., accompanied by Mr. C. H. Sinclair, who aided in the observations requisite. The determination in position of each of the 94 stations between Quoddy Head and Cape May was made by various methods. "As soon as the general locality was identified on the maps, angular measurements were taken on permanent objects, such as light-houses, old buildings, sharp points of topography, and particularly on stations that had been occupied for triangulation in the Coast Survey. Linear measurements were in all cases to objects that were not too remote from the life-saving station, and the general topography was referred to when that on the plane-table sheet showed that no change had occurred in natural features." For the present, stations were passed by at which no reference-points have been as yet determined; but these will in time be included, when the positions can be ascertained incidentally and without incurring any considerable outlay.

The report of Assistant Gerdes at the end of the season was accompanied by two quarto notebooks containing his field-records and sketches, and the angular and linear measurements made in the progress of the work. At the office, the notes were carefully examined with respect to the latitude and longitude assigned for each of the stations, and the result, when accepted as complete, was applied in each case with a note of the date on which the determination was made.

Hydrography near Plymouth, Mass.—In the vicinity of Plymouth, Mass., supplementary soundings were made by Assistant F. F. Nes, in September, 1875. Across the entrance to Plymouth Harbor the hydrography was revised, and also along the eastern side of the spit, between Pier Head Station and Clifford House. Further eastward, soundings were made along the shore from Rocky Point southward to Manomet Point, including the vicinity of White Horse Rock. Five shore-signals were erected for this work, and angles were observed on thirty-nine stations. The ordinary hydrographic statistics are:

Miles run in sounding	109
Angles with sextant	367
Number of soundings	4,413

While prosecuting the supplementary soundings, observations were recorded for determining the level of mean high water, and also that of mean low water.

Assistant Nes was subsequently engaged in similar work on the coast of Maine, as already mentioned, and previously on the coast of Long Island, as will be noticed under the head of Section II.

Plymouth Harbor, Mass.—Assistant Henry Mitchell has pointed out, after comparing old and new maps of the vicinity of Plymouth, that a very large deposit has taken place in the outer roadstead, south of Brown's Island, since the visit of De Mons and Champlain in 1605, and an equally remarkable deposit in the main ship-channel since the survey of Charles Blaskowitz in 1774.

In Appendix No. 9 is given for purposes of reference hereafter the condition of this port for the two early dates, compared with the condition found by the Coast Survey, allowing only the limited credit due to old maps in respect of accuracy. The fact that these deposits have been made in the deepest places without much alteration of shore-line (judging from the old maps) has led Professor Mitchell to conclude, as may be seen by his paper in the appendix, that part of the material has been brought into this vicinity by the Barnstable Bay current, which he discovered and reported on when assisting the United States commissioners in 1860–'61 on the proposed route for a ship-canal across Cape Cod. This current sweeps around the bay, pressing upon the western shore, and from its low temperature is believed by Mr. Mitchell to be an outcrop of a stream *following the bottom* on its way from the ocean. Such a stream, it is evident, might move material along the bottom and cause a deposit in any pocket, or re-entrant angle met in its course. The localities most subject to change in the section here under notice were surveyed last in 1853. A resurvey not being needed now for practical purposes, the general circumstances affecting the vicinity are put on record for action when the matter brought to notice by Assistant Mitchell can be tested incidentally.

Hydrography near Monomoy Point, Mass.—With the steamer Bache, a party in charge of Lieut. Commander J. C. Kennett, U. S. N., assistant in the Coast Survey, commenced soundings at the eastern approach to Nantucket Sound on the 29th of July, 1875. The hydrography was extended north and south from the Pollock Rip light-vessel about twelve miles and twenty miles to seaward. Inshore soundings were also made along the eastern side of Monomoy Point, the work extending about five miles along the beach, above and below the light-house. Acting Ensign George Glass was attached to the party in the steamer Bache. Hydrographic operations were closed on the 24th of September. The following synopsis appears as statistics on the working-sheet:

Miles run in sounding	224
Angles measured	915
Number of soundings	5,385

After closing this service the steamer was refitted for the performance of duty, which will be referred to in this report under the head of Section VI.

Hydrography of the Handkerchief Shoal (*Vineyard Sound*).—This work was begun by Lieut. R. D. Hitchcock, U. S. N., assistant in the Coast Survey, on the 28th of August, 1875, with his party in the steamer Gedney, and was closed on the 9th of October, after which date the vessel was refitted for duty, which will be mentioned under the head of Section VII.

While sounding on the Handkerchief the tides were observed at Powder Hole, on the west side of Monomoy Point. The space sounded includes about four miles of the south part of the shoal adjacent to the light-vessel. East and west the lines run in soundings averaged nearly three miles. The general statistics of the work are:

Miles run in soundings	74
Angles measured	270
Number of soundings	4,890

Lieut. James Franklin, U. S. N., assisted in this service, and also in Section VII. Masters John Hubbard, H. C. T. Nye, and J. L. Hunsicker, U. S. N., were attached to the party in the steamer Gedney.

On the 1st of September Lieutenant Franklin was rescued from imminent peril by Masters Nye and Hunsicker at the risk of their own lives. Becoming suddenly exhausted while swimming, the lieutenant was swept astern by the tide. The young officers plunged overboard instantly, and though much exhausted in the effort, sustained Mr. Franklin, who was then insensible, until all were taken from the water by a boat from the Gedney.

In recognition of the prompt gallantry by which the life of their messmate was saved, the Humane Society of Massachusetts issued silver medals, properly inscribed, to Masters Nye and Hunsicker.

While sounding on the Handkerchief Lieutenant Hitchcock was informed that a wreck had sunk on Pollock Rip in the track of vessels. Proceeding to the place the wreck was found in seven fathoms, but dangerous while the spars held. A mark was placed to warn vessels from the wreck, and notice was sent to the Light-House Board with recommendation for the placing of a buoy.

Topography of Taunton River, Mass.—In continuation of this survey Assistant A. M. Harrison resumed field-work on the 13th of July, 1875, below Fall River, and prosecuted the topography of the banks of Taunton River steadily until the close of November. Including the ground mapped last year in the vicinity of Somerset, when the triangulation of the river was advanced from Prudence Island to points within three miles of the city of Taunton, the plane-table work has produced seven sheets of which the details are full, and the scale ample for any purpose of future local improvement. In its progress up the river the survey included Assonet Bay and River, a tributary of the Taunton, the wharf outlines at Fall River, and the villages of Somerset, Dighton, Berkley, and Weir. The immediate vicinity of Dighton Rock was also mapped separately on a large scale, and such particulars of interest concerning it as Mr. Harrison was able to gather by incidental research were embodied in a separate paper and filed in the office.

The ground surveyed along the banks of the Taunton presents the usual topographical characteristics peculiar to a long-settled river-district. Contour-lines on the plane-table sheets show successive elevations of ten feet along the banks as far up as Broad Cove. Between Broad Cove and Weir Village the lines were traced to show each rise of five feet in ground above the water-line.

Assistant Harrison was aided in the field by Messrs. Bion Bradbury and W. B. French. The following are statistics of the field-work:

Shore-line surveyed, miles	56
Marsh, creeks, and ponds, miles	54
Roads, miles	31
Area of topography, square miles	12¼

Mr. Harrison is now engaged in prosecuting the detailed survey in the vicinity of Taunton.

Tidal observations.—From the self-registering tide-gauge lent to the city of Providence, records of four consecutive years, ending with the year 1875, have been received from J. H. Shedd, esq., civil engineer. These were accompanied with registers showing the tabulated high waters and low waters and the hourly ordinates. The series is marked by frequent interruptions which occurred especially in winter, but will ultimately be useful for discussing the tides of Narragansett Bay. The instrument is yet in use at Providence for surveys relative to a system of sewerage and other local improvements, and the expense attending the management of the gauge is consequently borne by the city authorities.

Light-house positions.—In continuation of similar work prosecuted in the preceding fiscal year, Assistant J. A. Sullivan took the field at Greenport (Long Island, N. Y.) on the 1st of July, 1875. In the course of the season, which was closed November 8, following, the positions of twenty lights were determined between Wood's Hole, Mass., and Greenport, N. Y. The determinations include the lights at Cedar Island, Long Beach, Block Island, Faulkner's Island, Manhasset, Bass River, Hyannis, Nantucket, Brant Point, South Bay and North Bay, Edgartown, Cape Poge, West Chop and East Chop, Gay Head, Nobska, Palmer's Island, Wing's Neck, and the light on "Bishop and Clerks," a shoal off Hyannis. These are distributed at intervals in a stretch of about a hundred and forty miles along the south coast of New England. Exclusive of the permanent lights the positions of four light-ships and of sixteen fixed objects on land were ascertained by observations with the theodolite. The general statistics of the work are:

Signals erected	18
Stations occupied	23
Angular measurements with theodolite	2,850

SECTION II.

ATLANTIC COAST AND SEAPORTS OF CONNECTICUT, NEW YORK, NEW JERSEY, PENNSYLVANIA, AND DELAWARE, INCLUDING BAYS AND RIVERS.—(SKETCHES NOS. 6 AND 7.)

Triangulation of Connecticut River.—In a previous year stations had been determined along the lower part of Connecticut River. For extending the work upward Assistant R. E. Halter took the field at the opening of the present fiscal year. He readily identified the stations at which the oper-

ations had been discontinued, and selected others as high up as Hartford. These in succession were occupied with the theodolite, and from them subsidiary points were determined for use in the topographical survey. The triangulation of the river was connected with the primary work by occupying Box Hill, a point well determined in the general triangulation of the coast of New England. Field-work was continued until the middle of October. Mr. Hugh Caperton served as aid in the triangulation-party. The statistics of work are:

Signals erected	16
Stations occupied	14
Sets of observations (six repetitions each)	525
Number of observations recorded	6,698

After completing the records and computations of his work, Assistant Halter made arrangements for field-service on the coast of Texas, as will be mentioned under the head of Section IX.

Topographical survey north of New Haven, Conn.—This work has been prosecuted by Assistant R. M. Bache, with the aid of graduates from the Sheffield Scientific School. In order to connect the plane-table survey with the detailed topography of the harbor-shores, a tertiary triangulation was made to include the district between Woodbridge and North Haven, and extending northward to Mount Carmel. Within that region lines were carefully run with the spirit-level to an aggregate of twenty-two miles to establish bench-marks for contouring. The topography is in close detail, and special care has been manifested in the delineation of surface-features. Assistant Bache took the field in July, 1875, and prosecuted the survey until the following January. The party was then disbanded, and the maps resulting from the field-work were inked and completed by the middle of April. In May last Mr. Bache resumed the topographical survey. Mr. Horace Andrews, as heretofore, served as principal aid, with other members of the Sheffield school, selected for their steady interest in the work. The details mapped in the course of the year make the following aggregate in statistics:

Shore-line of river, creeks, &c., miles	110
Roads, miles	138
Area of topography, square miles	29

Hydrography of Cumberland Shoal.—Between September 11 and 25, 1875, the passage between Plum Island and Gull Island, and to the northward and eastward of it the rocky bed known as Cumberland Shoal, were sounded by Lieut. C. T. Hutchins, U. S. N., with a party in the steamer Endeavor. Middle Rock was plotted in position from angles taken with theodolites on Little Gull light-house and Gardiner's Point light-house, and for verification the rock was occupied with a sextant for measuring the angle made there by lines leading to the light-houses.

"Between Middle Rock and the eastern end of Plum Island lies between two rocks an old boiler, part of the wreck of one of the revenue-cutters. The boiler readily offering for the purpose, its position was accurately determined, and the rocks were located accordingly on the chart. In range with them, and about three hundred and fifty yards from the beach of Plum Island, a rock was found with only six feet of water on it at low tide. The channel between the island and Middle Rock is rocky and dangerous."

On Cumberland Shoal the least depth found was 3¼ fathoms, in a position corresponding to that assigned by Captain Breese, U. S. N., when the United States ship Constellation, under his command, struck a rock off the east end of Long Island in the preceding year. Because of the limit in time available for the work near Plum Island, the state of the tides was not recorded while the soundings were in progress; hence the depth here mentioned is to be understood as corresponding to the reduction called for by applying a prediction for the state of the tide when that particular sounding was recorded.

The statistics of the work are:

Miles run in sounding	51
Angles measured	1,574
Number of soundings	3,260

Lieutenant Hutchins was assisted in this section by Master S. H. May and W. M. Wood, and

by Ensign H. McCrea, U. S. N. The party was subsequently in hydrographic service, as will be seen under the head of Section V.

Triangulation.—In continuation of the field-work in this section, Assistant Richard D. Cutts, after needful preparation, occupied Mount Rafinesque, near the eastern border of the State of New York, early in July. The aid in the party, Mr. J. F. Pratt, as soon as practicable, cleared the lines of sight on the summits of Mounts Equinox and Greylock, and brought the respective signals into view from the theodolite-station.

The measurement of horizontal and vertical angles was begun at Rafinesque on the 1st of August. When the records were complete for that station, the party was transferred to Greenwich Hill, a station about twenty-five miles to the northward, where similar series of measurements were recorded by the 7th of October. A few days after the instruments were moved to South Adams, in expectation that the weather might admit of occupying the primary station Greylock before closing field-work for the season. The summit of Greylock, however, was covered by snow on the 13th of October, and no ready means were at hand for the transfer of instruments to the station. A suggestion made by Mr. Cutts to leading residents in South Adams, in regard to the advisability of having a road by which tourists might reach the top of the highest mountain in the State, was favorably received. That station being next in order in the primary series, the field-work was closed, and the party disbanded at South Adams, to resume in the summer of 1876. On returning to the station with his party in June of the present year, Assistant Cutts was gratified to find that the promise of the inhabitants had been fulfilled. By a practicable road, constructed during his absence, the party and instruments were moved to the summit of Greylock, which is about 3,500 feet above tide-water. When this report closes, Mr. Cutts had all preliminaries arranged for the measurement of horizontal and vertical angles. The statistics of work at the stations Mount Rafinesque and Greenwich Hill, which were occupied in the summer and autumn of 1875, are:

Horizontal angles measured	17
Number of measurements	1,008
Vertical angles	14
Number of measurements	180

While personally engaged in the field-work of his own party, Assistant Cutts was in correspondence with several observers who were at the same time prosecuting work for the determination of points to aid in the geological surveys of several of the seaboard and interior States. The work here referred to will be mentioned under separate heads in this report, and in accordance with the geographical positions of the several localities.

Coast Pilot.—As already stated under the head of Section I, the party of Assistant J. S. Bradford, in the schooner Palinurus, arrived at New York soon after the middle of July, 1875. The weather was exceptionally rainy during that month and the following, but advantage was taken of every opportunity for examinations in New York Bay and its tributaries, with reference to notes and revisions for the Coast Pilot. The last three weeks in August were spent in similar service on the Hudson River. Mr. Bradford then transferred his party to the coast of Maine, but returned to this section early in November. In passing Block Island Sound, views were taken by Mr. J. R. Barker, the draughtsman attached to the party, and thence on westward to Sandy Hook all points of interest were sketched as features for completing the local or general charts within the same limits. The artistic skill and faithful accuracy evidenced by the views are subjects of special remark in the final report of Assistant Bradford. Lieut. C. A. Bradbury, at the outset of the season, was attached to the party in the Palinurus, and acted as executive officer and sailing-master while the vessel was in service on the coast of Maine, and also in this section. He had in the course of the season observed the methods for procuring and arranging the data intended for the Coast Pilot, and with a view to continuing that work he assisted in the details of the service in New York Harbor until the 1st of December, when the vessel sailed for Norfolk. A few days after, the Palinurus was transferred to the charge of Lieutenant Bradbury, and was employed subsequently in duty on the southern coast, as will be mentioned further on in this report.

During the winter, Assistant Bradford prepared for publication the manuscript of a second vol-

ume of the Coast Pilot, to include ports and harbors between Boston and New York. The series of views needful for this volume was completed in June of the present year, by the co-operation of Capt. A. C. Rhind, U. S. N., light-house inspector of the third district. The steamer Putnam, courteously tendered by Captain Rhind, was at the service of Assistant Bradford during four days, and in that interval eleven views were drawn by Mr. Barker of points of interest along the Hudson. These, with previous sketches, make an aggregate of fifty-nine views of the Atlantic coast between the northeastern boundary and New York. Most of them have been etched on copper, and the plates are ready for printing. Those taken in this section comprise two views of Montauk Point, two of Fire Island Inlet, one of the Highlands of Navesink, and sixteen views of points on the Hudson River.

When the failing health of Mr. Edwin Hergesheimer, in March last, rendered him unable to conduct the details of work in the Engraving Division of the office, Assistant Bradford was assigned to that charge, keeping meanwhile in hand the adjustment of materials for the Coast Pilot, in which he has been aided by Mr. J. W. Parsons.

Shore-lines of New York Harbor.—With five sheets projected for the purpose, Assistant H. L. Whiting took the field early in July, 1875, and by the end of October traced and mapped the shore-line as it then existed for the greater part of New York Bay. One sheet represents in outline the Narrows as high up as Bay Ridge and Snug Harbor Landing; another contains the shore-line and wharf-details from Owl's Head below Gowanus Bay and the water-front of Brooklyn; the navy-yard; the vicinity of Newtown Creek, and features above it as far as Astoria. On a third sheet, containing the wharf-outlines of Jersey City, the detailed work was extended above Castle Point to Guttenberg, and was continued on a fourth sheet as far as Bull's Ferry. The fifth sheet shows in position the quarantine piers in New York Bay. Assistant Whiting was aided in this work by Mr. R. B. Palfrey.

Physical survey of New York Harbor.—The study of the tides, currents, and character of the deposits in New York Harbor has been continued by Prof. Henry Mitchell, and the advance made justifies the publication of some of the resulting tables, which will be found in the appendix (No. 10), with explanatory remarks by Mr. Mitchell, who directed the observations.

The practical uses to which such tables may be applied for locating harbor-lines, adjusting riparian interests, and accommodating private to public purposes in the extension of water-frontage for commerce, will be obvious on examination. The completion of physical research will reveal also the mutual relations of different parts of the harbor and its numerous channels, and thus the injury. even distant and indirect, that will be likely to result from irregular or excessive encroachment may be predicted with confidence.

This survey has, of necessity, been prosecuted at intervals, and differing considerably in date the observations could be reconciled only by a large amount of office-work. Points that have relatively the least force in the compiled data are indicated in the report, so that reliance may not be misplaced.

The tables show the *transverse sections*, the *curve of velocity* from shore to shore, the points about which the areas and volumes balance each other (mid-area and mid-volume), &c. From these data the relations of the channels to the streams which traverse them may be known in a general way, though the diversity of material of beds and banks in partly alluvial, partly rocky neighborhoods somewhat complicates the phenomena.

The plan for observations in each season, after being arranged by Mr. Mitchell, is intrusted for the prosecution of details to Assistant H. L. Marindin with a party in the schooner Research. Mr. J. B. Weir served as aid in this section and also in Section VIII, under which head notice will be made of the subsequent work of the same party.

The statistics of the work done in New York Harbor during August, September, and October, 1875, are:

Stations occupied	8
Signals erected	10
Current-observations	4, 783

Tidal observations were recorded at five stations. Seventeen transverse sections were determined by observations at ninety-six positions in the sections. Assistant Mitchell reports that the space from the Narrows up to Seventy-ninth street, on the Hudson, and to Hell Gate on the East River, may now be regarded as gauged in accordance with the plan marked out in the beginning of the physical survey.

After the completion of a local survey, which will be mentioned under the next head, Lieut. H. O. Handy, U. S. N., assistant in the Coast Survey, with his party, in the steamer Arago, co-operated with Assistant Mitchell in regard to details in the physical survey of New York Harbor. During September and October, 1875, the Arago worked in conjunction with the schooner Research in determining currents in Hudson River, in New York Upper Bay, and in the east channel of East River. Twenty-three stations were occupied along ten lines. The positions were ascertained by the measurement of eight hundred and fifteen angles, and the velocity of the current by fourteen hundred and thirty-two observations. While the Arago was employed on the sections for recording currents, tidal observations were simultaneously recorded at Governor's Island, and at two stations in East River.

Lieutenant Handy was assisted in this service by Master W. P. Ray and Ensign F. H. Lefavor, U. S. N. Closing work on the 2d of November, Lieutenant Handy, a few days after, passed the steamer through the Delaware and Raritan Canal, and laid up the vessel at Baltimore.

Shrewsbury Rocks.—For developing by soundings the vicinity of the rocks off Shrewsbury Inlet, south of Sandy Hook, Lieutenant Handy, with a party in the steamer Arago, made preparation late in July, 1875. As the best available point on shore, the position of the telegraph-station was determined for reference in sounding. While the work was in progress the tides were observed at the government wharf at Sandy Hook during each five minutes of the day. The hydrography was prosecuted at all intervals admitting of work between the 9th and 30th of August, but the weather was generally unfavorable. The statistics of the work are:

Miles run in sounding	55
Angles measured	578
Number of soundings	1,524

The subsequent work of the party in the Arago was mentioned under a preceding head, in its proper geographical order.

Tidal observations.—The series of tidal observations at Governor's Island, in New York Harbor, has been continued through the year very successfully by the observer, Mr. R. T. Bassett. Though of the old form, the apparatus, by the experience and care of Mr. Bassett, was made to work well throughout the winter, with the free application of hot water when ice was likely to impede action in the float of the gauge. The same observer recorded day-observations with a box-gauge at Hamilton Avenue Ferry, in Brooklyn, for comparison with the series at Governor's Island.

In my annual report for the year 1875, a paper was given showing the results of discussion by Prof. William Ferrel, based on the continuous series of tidal observations which have been maintained at the permanent station in New York Harbor.

Triangulation near New York City.—As incidental to the determination of latitude and azimuth at Beacon Hill, N. J., one of the primary stations occupied at an early period in the survey of the coast, Assistant G. W. Dean, in the course of the summer of 1875, connected that station by angular measurements with the principal points used in the survey of New York Harbor. Careful reconnaissance resulted in the selection of eleven stations, at seven of which signals were set up. The daily smoke near the city, as was expected, much delayed the measurement of horizontal angles at Beacon Hill, where, however, other work was in progress during the season, as will be stated under the next head. The statistics of the triangulation are:

Signals erected	7
Angles measured	11
Number of observations	1,246

The angles at Beacon Hill were measured with a 12-inch repeating theodolite. Assistant Dean was aided in this service, and also in astronomical observations, by Messrs. J. B. Baylor and Charles Tappan.

Latitude and azimuth at Beacon Hill, N. J.—The station-marks placed at Beacon Hill in 1839 having been identified, as mentioned in my last annual report, and provision made for mounting the requisite astronomical instruments, Assistant Dean was there in readiness at the close of July, 1875, for determining azimuth with the 46-inch transit, No. 5. The instrument was adjusted on a brick pier, directly over the geodetic station. Measurements made with the micrometer upon the star δ Ursæ Minoris near upper, and on 51 Cephei near its lower culmination, were referred to a meridian-mark about eight miles north of Beacon Hill. One hundred and seventy-nine observations were recorded on six nights. The angle between the meridian-mark and the primary station on Weasel Mountain, in the northern part of the State of New Jersey, was carefully measured with a 12-inch theodolite.

At Beacon Hill, Mr. Baylor, in observing for the latitude with zenith-telescope No. 4, recorded one hundred and eighty-one measurements upon thirty-two sets of stars. For ascertaining the arc-value of the micrometer, one hundred and sixty-four observations were made upon Polaris near eastern elongation. The level-scale was determined in value in the usual manner from sixty-four measurements with the micrometer. Local time was obtained from five hundred and thirty-four observations upon thirty-one zenith and circumpolar stars with the transit-instrument No. 5.

The field-operations here noticed were closed in November, 1875. In the course of the winter and spring the resulting computations were made and sent to the office with the originals and duplicates of the record of observations.

Hydrography of Fire Island Inlet, N. Y.—In August, 1875, this inlet was examined by Assistant F. F. Nes. Considerable changes in shore-line were observed as having taken place in the course of two years on the eastern side of the entrance. The soundings showed, however, no material change in the general course of the channel. Mr. Nes erected five signals for this survey, and under his direction the tides were recorded during nineteen days. The general statistics of the work are:

Miles run in sounding	254
Angles measured	199
Number of soundings	1,673

Work done subsequently by Assistant Nes has been mentioned under Section I.

Triangulation west of Fire Island Inlet, N. Y.—In order to provide for the detailed survey of the south coast of Long Island, Subassistant B. A. Colonna was assigned to field-duty early in July, 1875, to determine stations in position between Fire Island Inlet and Rockaway. Two points previously occupied with the theodolite in the vicinity of Babylon having been identified, stations visible from them and from each other were selected and connected by angular measurement. The scheme, as far as completed, extends westward to Far Rockaway. To connect his series of triangles with the primary work, Mr. Colonna occupied West Hills station and completed observations there on the 28th of October. Fifty points were determined in position in the course of the season. The general statistics of the triangulation are:

Signals erected	21
Stations occupied	15
Angles measured	248
Number of observations	6,950

This work was pushed under natural disadvantages in passing from station to station in summer through shallow waters in an open boat, and in which the party sometimes remained all night because of the distance from more acceptable sleeping-quarters. All positions occupied with the theodolite were well secured by surface and underground marks before the party left this section. During the winter, Subassistant Colonna was on field-duty in Section VIII.

Survey of Great South Bay, N. Y.—This survey was resumed on the 14th of July, 1875, by a party in charge of Assistant C. T. Iardella. Beginning with the plane-table near Patchogue, the details of topography between the shore-line and the road running parallel with it were mapped as far as Carman's River. Farther eastward the work done includes several miles of the course of that river, the head of Great South Bay as far as Roberts' Dock, and about five miles of the barrier

which separates the bay from the ocean. Among the details represented are the several small islands in the bay opposite to Howell's Point.

Within the shore-line limits of the plane-table sheet here noticed, Assistant Iardella completed soundings in Great South Bay, and then transferred his party to the vicinity of Babylon, for continuing the detailed survey westward. In that quarter the railroad was taken as the limit of work. East and west, the shore-line and surface-features were mapped between Conklin's Point and Neguntatogue Creek.

Assistant Iardella was aided in this work by Mr. W. Fraser. The party was disbanded at the end of October. A synopsis in the field-report gives as statistics:

Shore-line surveyed, miles	48
Streams and ponds, miles	18
Roads, miles	61
Area of topography, square miles	10
Miles run in sounding	139
Angles measured	688
Casts of the lead	9,670

Tidal observations.—As intimated in my previous report in regard to the erection of a tide-gauge at Sandy Hook, when the arrangements needful were complete, Mr. R. S. Avery, of the Tidal Division of the Coast Survey Office, proceeded to the vicinity early in October, 1875. Under his supervision a structure five feet by eight, for covering the tide-gauge and high enough to stand in, had been made in sections and was forwarded to the place. The self-registering gauge designated for use at Sandy Hook is of the best construction and is furnished with a balance-clock, reading-box, and all accessories requisite for preserving continuity in the series of observations. With the sanction of W. S. Sneden, esq., general manager of the Southern New Jersey Railroad Company, the tidal apparatus was fastened securely to the middle of a wharf about 60 feet wide, and far enough from the outer end of the wharf to be free from the jarring action of the ice of Raritan Bay when it is driven by strong wind from the westward. The float-box of the gauge was let down through a square opening in the deck of the wharf, and is protected on all sides by a great number of piles that stand upright to bear up the wharf and its burdens of freight. At maximum tides the water under the tide-gauge is about 20 feet deep. After bracing the float-box firmly in its proper place the tide-house was set up and fastened to the wharf by screws passed through the sills of the house and into the wharf-planks. Part of the roof is put on with screws to admit of taking up, if needful, either the inner float-tube, or both. The piling that sustains the wharf will not allow the passage of cakes of ice greater than four feet in width, but to guard against possible injury to the float-box a crib was made around it by spiking 2-inch Virginia pine plank firmly to three of the piles nearest to the box, which is nearly 17 feet long and 6½ inches square. It was constructed at the office, and inside as well as outside is covered with sheet-copper, slips of which were continued over the ends. When corroded at the lower end the box can be reversed and continued in use. Inside of the float-box was placed a round tube of five inches and eight-tenths aperture supported by a flange at top and terminating at the lower end with a funnel of which the aperture is only three-quarters of an inch to admit the water. The float is a hollow water-tight copper cylinder 5 inches in diameter and 4½ inches high, and was adjusted so as to float erect with the rise and fall of water in the cylindrical tube. A plan devised by Mr. Avery and applied in the tide-gauge set up on Sandy Hook will be understood by the following extract from his report:

"Two lines run up from the copper float, one, a round, well-varnished fish-line, to connect with the large wheel of the gauge as usual, but the other is part of a surveyor's tape-line, the chain of it being brass or copper wire, and the filling of linen thread. The tape is painted and marked in feet. This goes over a pulley of 6 inches, having on its axis another pulley of 2 inches diameter for a counterweight, which is just sufficient to keep the tape-line straight. These pulleys run in a frame attached to the roof of the tide-house, and are so placed that the line can run down in the middle of the float-box, and in so doing pass along the side of a staff, one foot of which, at the height of the eye, is graduated in tenths and hundredths, to serve as a vernier. While the water was oscillating as much as 2 feet up and down at the plain tide-staff (spiked up for the purpose), the height

of tide was read to the nearest hundredth on the tape-line, before the work about the tide-house was completed."

For bench-marks, Mr. Avery sunk two cedar posts at the edge of a grove of red cedars, which border the marsh at a point nearest to the tide-gauge. Each of the posts was marked with copper nails, and was set in ground a few feet higher than the marsh, where natural changes will be very slow and artificial works not likely to be called for. By estimation, the bench-marks are about one hundred rods northeasterly from the tide-house.

The gauge at the neck of Sandy Hook was placed in charge of Mr. J. W. Banford, a very intelligent employé of the railroad company. Since October, 1875, when the apparatus was put in running order, a very good set of observations had been made, though the water is often agitated more than is usual at tidal stations. Nearer to the point of Sandy Hook, where the violent action of ice, driven by storms in winter, had crushed the outer piling of the government wharf, it was deemed inexpedient to establish the tide-gauge, which, for that reason alone, was put in operation at a position more distant from the point of the Hook, where it would be less exposed to the violence of the sea.

Topography, coast of New Jersey.—For completing the plane-table survey at the north end of Barnegat Bay, Assistant C. M. Bache took the field in the latter part of July, 1875. Joining with the limits of his previous work below Tom's River, that stream was included in the survey as far up as the town so named. The coast-line and shores of the bay were then traced, including on the western side Mosquito Cove and Kettle Creek. A short distance above the latter, the work was joined with the general topographical survey of the coast, which is now continuous from Sandy Hook to a point several miles below Atlantic City. The nearest road following the western shore of the bay was taken as the limit of the survey inland. Mr. A. G. Pendleton joined this party as aid early in August, and remained in service till the close of work on the 8th of November. The statistics are:

Shore-line surveyed, miles	109
Roads, miles	117
Area, square miles	43

After laying up the barge which had been used by his party in the survey of the coast of New Jersey, Mr. Bache returned to Philadelphia and there completed and inked the sheet containing the season's work.

Triangulation in New Jersey.—The requirements of the geological survey, which has been some time in full activity under the direction of Prof. G. H. Cook, the State geologist, have been met by Prof. E. A. Bowser, who took the field late in June, 1875, and passed several months in selecting points suitably related to stations of the Coast Survey. His reconnaissance included about seven hundred square miles, within which nineteen stations were selected and marked. These will be hereafter occupied with the theodolite for the measurement of horizontal angles. In general, the triangle sides will range from six to nineteen miles in length, over a region varying from four hundred to twelve hundred feet above tide. As far as now advanced, the reconnaissance includes the northern part of New Jersey, and extends southward from the boundary between that State and New York to Newtown and Mount Rose, where the scheme joins with the Coast Survey primary triangulation. Similar work being now in progress westward from the Delaware, the reconnaissance on both sides, to be effective for all future purposes, must keep in view the selection of two or more points at which both schemes of triangulation will join. The labor and hardship involved in the selection of intervisible points over a wooded country are commonly very considerable where the region offers no well-defined elevations. To the sameness of the hills in contour, and the consequent difficulty of identification, the observer finds added the dense undergrowth through which lines of sight must be cut, and which, notwithstanding the labor, do not in all cases avail in perfecting the desired scheme of triangulation.

Closing for the season at the end of September, 1875, Professor Bowser again took the field early in March of the present year, and has improved the scheme as first marked out, by slightly altering the position of some of the stations. He reports the necessity of high scaffolds for the

theodolite at some of the points which, although favorably situated, cannot be seen from the stations adjacent without laborious and expensive cutting through the intervening timoer.

At the end of June, when this report was closed, the reconnaissance for station-points was still in progress, under the general direction of Professor Cook.

While conducting work with his own party in the field, as mentioned under a preceding head of this section, Assistant Richard D. Cutts advised by correspondence in regard to the reconnaissance in New Jersey, and also for the examination then in progress in Eastern Pennsylvania, which will be the next subject of notice.

Triangulation in Eastern Pennsylvania.—As stated in my report of last year, arrangements had been made for determining points in the vicinity of the Lehigh Valley by Prof. L. M. Haupt, in accordance with the wishes of Prof. J. P. Lesley, State geologist of Pennsylvania.

Professor Haupt took the field on the 1st of July, 1875, and, giving attention to the means for joining with known points of the primary triangulation which passed some years ago along the Delaware River through the State of New Jersey, stations were selected at *Smith's Gap* and *Bake-Oven Knob*, the latter being a conspicuous elevation of the Blue Ridge. From that station reconnaissance was extended northward to Broad Mountain, and in other directions, but under some disadvantage, as most of the summits deemed available, when visited were found to be cumbered with underbrush and trees that hindered the view. Ultimately, a point was selected on Broad Mountain, and to the southward another near Topton. Other stations to the westward were chosen in succession, and by the 11th of September an acceptable scheme of triangulation had been laid out reaching to points westward of Reading. A few preliminary measurements were made, but the purpose is to complete the scheme previous to the final measurement of horizontal angles.

Professor Haupt left Philadelphia on the 19th of June of the present year, and resumed reconnaissance for perfecting the connection between his own and some geodetic stations which had been selected by another observer on the east side of Delaware River in New Jersey. Until the close of the month the region south and west of the Delaware Water Gap was carefully examined. The work is in progress when this report closes, and the prospect is good for developing before the close of the season a satisfactory scheme of points to include the ground between the Delaware and the Susquehanna Rivers.

For the immediate purposes of the geological survey, Professor Haupt measured a short base-line, and recorded the approximate readings of angles at several of the stations. These operations will be repeated systematically when the positions are hereafter occupied with the theodolite. The six stations now marked will form two well-shaped quadrilaterals from which the scheme of triangulation can be readily extended westward or eastward. The triangle sides vary from sixteen to thirty miles in length. On the east and south this triangulation will be properly connected with the chain of great triangles that defines the outline of the coast along the Middle States.

To further the means for determining points in Eastern Pennsylvania, Assistant G. A. Fairfield was directed, in the autumn of 1875, to seek for the ground-marks which had been set at the primary tations Principio and Osborne's Ruin when the triangulation of Chesapeake Bay was in progress. One of these stations is on the east side of the Susquehanna and the other on the western side. Principio had been identified in 1866, and Mr. Fairfield readily found the station-mark. The ground at Osborne's had not been disturbed since the station was first occupied. Within the limits indicated by the reference-marks the cone was found where it had been first buried. On looking to the northward from these two stations no points were in view favorable for extending the triangulation in that direction. Proceeding to the northward and eastward, Mr. Fairfield visited the station at Meeting House Hill, and there found, without difficulty, the station-mark in the position in which it was placed thirty-five years ago. The base being sufficient for the addition of subsidiary points if the ground in Southeastern Pennsylvania proved favorable for triangulation, Assistant Fairfield made a reconnaissance through Chester County and noted such points as might be available for extending the triangulation northward. On the approach of severe weather the reconnaissance was discontinued, but will be resumed hereafter.

Hydrography of Delaware River.—With a party organized for service on board the steamer Fathomer, Lieut. J. M. Grimes, U. S. N., assistant in the Coast Survey, took charge of that vessel at New

York in July, and, after needful repairs, passed through the Raritan Canal and reached Delaware City on the 20th of August, 1875. The work assigned in that vicinity was the extension of soundings along both sides of the main channel between Delaware City and Ship John Shoal Light. Eleven signals were erected by the party in the Fathomer, and their positions were determined by occupying thirty stations. While soundings were in progress, the tides were observed and recorded at a wharf in Delaware City and also at Reedy Island. Considerable changes were noticed as having occurred in the shore-lines, the river-bank receding in some places and advancing in others.

In midchannel and S. 25° 35′ E. (true), distant 2,503 meters from Reedy Island light-house, Lieutenant Grimes developed a shoal on which the depth is 19½ feet at mean low water. Having filled with soundings the projection sent for this part of the river, the Fathomer was moved up to a position between Marcus Hook and Chester, in which vicinity a ledge was developed by careful soundings in October. This impediment in navigation seems to have been caused by a sunken schooner or sloop which became imbedded in the sandy bottom between some rocks. Hence in the notice to mariners, which issued from the Coast Survey Office early in November, the danger is named Schooner Ledge. As far as practicable with the means at hand, all the rocks in the vicinity of the place were developed and marked on the chart. The statistics of hydrographic work in the Delaware are:

Miles run in sounding	315
Angles measured	3,602
Number of soundings	25,101

Lieutenant Grimes was aided in this work by Mr. C. A. Ives. The steamer Fathomer was subsequently employed in service which will be noticed under the head of Section IV in this report.

Liston's Tree range-lights.—The expediency of a range on the New Jersey side of the Delaware, in lieu of one of the two ranges marked last year on the west bank of that river, having been decided in the Light-House Board in February, the service was committed to Mr. Charles Junken. After consultation with General W. F. Raynolds, engineer of the fourth district, who had arranged for the purchase of sites, the requisite observations were made by Mr. Junken. The positions of the range-points were marked on the ground and on the original chart of that part of the river, as also on a copy of the original which had been made for the uses of the Light-House Board.

Sites for range-beacons, Delaware River.—Request having been made by General Raynolds, engineer of the fourth light-house district, for topographical surveys of the two sites selected on the west bank of the Delaware, near Liston's Tree, the work was committed early in July, 1875, to Messrs. F. C. Donn and F. H. Parsons, aids in the party of Assistant J. W. Donn, who was then completing arrangements for work which has been mentioned under the head of Section I. The mapping requisite for the ranges was completed in the field on the 17th of July. Soon after, the sheets were forwarded to the Light-House Board, and the two aids joined the party to which they had been previously assigned.

Shoal near Delaware Breakwater.—In June of the present year my attention was drawn to the existence of a shoal, reported by one of the bay pilots, near the Delaware Breakwater. Neither of the vessels of the survey being immediately available, the needful examination could not be made before the close of the fiscal year, at which time this report was closed. Arrangements were, however, promptly made for sounding the locality. The results will be stated in my next annual report, in which notice will be taken of all work prosecuted in the survey after the end of June, 1876.

SECTION III.

ATLANTIC COAST AND BAYS OF MARYLAND AND VIRGINIA, INCLUDING SEAPORTS AND RIVERS.

(SKETCH No. 8.)

Harbor of Baltimore, Md.—Local interest as manifested by the city authorities of Baltimore in regard to the preservation and improvement of the harbor, took definite form in May last, when the President of the United States authorized a board to confer with the governor of the State of Maryland, the legislature of the State having previously appropriated means for a special survey of the harbor. With the concurrence of the board, the members of which are General A. A. Humphreys, Chief of Engineers, C. P. Patterson, Superintendent United States Coast Survey, and Maj. William P. Craighill, of the Corps of Engineers, Assistant J. W. Donn was detailed in June, 1876, to make the survey which will be needful in the deliberations of the board for the establishment of bulkhead lines. Three sheets have been projected to contain the outline and hydrographic details of the inner harbor above its entrance at Fort McHenry. With an effective party, Assistant Donn is now prosecuting the desired survey.

Norfolk Harbor, Va.—As a preliminary to action by the harbor commissioners of Norfolk for the establishment of port-warden lines to restrict encroachments on the harbor, application was made in the usual way for an advisory board. At the first meeting of the members of the board it was deemed advisable to procure data of the kind which is very generally in requisition when measures are pending for the preservation of harbor channels. Fortunately, a very careful hydrographic survey had been made in 1873. It was needful only for the purposes of the board to determine, in addition, the dynamic axis in each channel, the curve of velocities from shore to shore, and the volume of discharge, as with such elements the problems involved in defining between artificial and natural limits are much simplified.

The requisite physical survey in the channels at Norfolk and Portsmouth was prosecuted under the direction of Assistant Henry Mitchell by Messrs. John B. Weir and E. H. Wyvill in May, 1876 Messrs. T. A. Harrison and C. A. Ives were attached to the party as aids, and the schooner Caswell was assigned for use in the work. The expenses incident to the special survey were met by the harbor commissioners of Norfolk.

Observations of the character shown in the appended statistics were recorded at numerous stations from the second bridge of Eastern Branch and the upper end of the navy-yard in the Southern Branch downward and beyond the bar to Lambert's Point light-house. The statistics are:

Angles measured	6,331
Number of soundings	3,016
Observations for velocity recorded	4,506

The tides were observed at four stations within the working-limits, and twenty-seven transverse sections were traced by an aggregate of two hundred and forty-six points.

Under Section VIII, notice will be taken of work previously done by Mr. Weir.

Tidal observations.—During the year, a self-registering tide-gauge, furnished with large interchangeable cylinders, reading-box, and a balance-wheel clock, has been kept in operation by Mr W. J. Bodell at the station on Old Point Comfort, Va. Interruptions in the series of observations at this station have ceased since the pendulum-clock was replaced by the one now in use. The wharf which supports the apparatus will soon be removed, but arrangements will be made to reoccupy the position on the engineer's wharf, at which the series was commenced some years ago.

Boundary between Maryland and Virginia.—Previous to the meeting of the boundary commissioners of the two States in June last at Crisfield, Md., request had been made by them for the services of a topographer of the Coast Survey to work under their immediate direction in mapping such ground as might be indicated in the course of their deliberations. Mr. Charles Junken, having been assigned for the special duty, reported in person to the commissioners at Crisfield, and commenced work on the 16th of June on Smith's Island. He was there engaged until the end of the

month. As the fiscal year then closed, the summary of his work will properly appear in my next annual report.

Triangulation.—Among the conditions requisite for final accuracy in triangulation is that the height of each of the primary stations above the sea-level should be known. Hence vertical angles are measured at the primary stations, and it remains only to refer the heights of a few stations near the coast to the level of the sea by running lines for that purpose with the spirit-level. For the chain of main triangles which passes near Washington City and follows the Blue Ridge in its course along the Atlantic seaboard, the plane of reference was ascertained in November, 1875. Assistant F. W. Perkins started from a well-determined bench-mark at the Washington navy-yard with a leveling-instrument, followed the line of the Baltimore and Potomac Railroad to its junction with the Annapolis Railroad, and thence passed down the last-mentioned road to Annapolis, where he established a mark at the level of mean tide. An offset was made from Wilson's Station on the railroad to the primary triangulation-point named Hills; and another offset was run across the Severn River at Annapolis to the primary station Taylor.

The main line of levels was begun at Washington on the 9th of November, and six hundred and thirty-four stations were made between the navy-yard and the level of Chesapeake Bay at Annapolis. By several well-marked objects the station there at which tides were recorded for one month was connected with the line of levels. All the lines were run twice. making in the aggregate eighty-six miles. Including the two lines of offsets, seven hundred and sixty-two stations were made. The two measurements for level show a close agreement. Mr. J. De Wolf joined the party on the 29th of November. Assistant Perkins was aided throughout by Mr. R. E. Duval. Operations were closed on the 24th of December. The work subsequently prosecuted by Mr. Perkins will be noticed under the head of Section VII.

Magnetic observations.—The usual annual determinations of the magnetic declination, dip, and intensity at the station on Capitol Hill in Washington City were made by Assistant C. A. Schott in April last, and by some weeks earlier than the period at which the observations have been annually made during the last ten years. The ground occupied being required for building purposes, a new station will be established in the vicinity.

As the instruments used in the observations here noticed are good specimens of their class, they were early in the summer sent to Philadelphia to form part of the Coast Survey exhibit in the Centennial Exposition.

Triangulation of James River, Va.—The schooner Scoresby, with the party of Assistant J. W. Donn, was at City Point in November, 1875, and it was then hoped that means might hold for extending the plane-table survey of the banks of the river as far as Richmond.

Several of the station-points which had been previously occupied in the triangulation of the main river near City Point could not be found, the marks having been wantonly destroyed. Mr. Donn in consequence found it necessary to begin his triangulation several miles below. During December, 1875, and January of the present year, points were selected and signals put up between Drewry and the approach to the city. Much labor was endured in prosecuting this work, as many of the lines of sight required heavy cutting through timber that abounds in the swamps bordering that part of the James River. Preliminary measurements of angles were made at all the stations, so that data might be available for topographical work, but Assistant Donn intended to make final measurements of the horizontal angles if means could be had for continuing the operations of the party during the spring. Other requirements of the service, however, made it necessary to recall the party in the Scoresby at the end of January, previous to which date twenty-three signals had been erected. During winter the vessel was docked at Richmond, there being, as against probabilities of running ice and freshets, no safe anchorage between the city and the point at which the work was resumed. Mr. Donn had been previously in Section I. On the James River he was aided by Messrs. F. C. Donn and F. H. Parsons.

Primary triangulation in Virginia.—At the opening of the fiscal year 1875–'76 field-work on the series of quadrilaterals which passes southward along the eastern side of the Blue Ridge had been extended to Humpback Mountain in Nelson County, Va., at which station observations were closed on the 2d of July, 1875. Assistant A. T. Mosman, as soon as practicable, transferred his

party to Spear Mountain, and closed the series of measurements requisite there on the 29th of August. At that station the weather proved to be unusually wet and foggy.

The station in the series of points named Tobacco Row Mountain was next occupied with the theodolite, and the angular measurements there required were completed on the 22d of September. Some of the lines which converge at this station were upward of fifty miles in length. The weather was often cloudy, but, on days suitable for observing, the signal-poles on the longest lines were in full view.

Preparations were complete on Long Mountain by the 12th of October for astronomical observations and for the measurement as usual of horizontal and vertical angles. The geodetic work was much delayed by the prevalence of smoke and haze, for some days in succession the outlying signals on long lines being hid from view. The astronomical observations were less hindered by the same cause. A lamp, set as an azimuth-mark in the belfry of the court-house at Lynchburg, which is about nine miles distant from the station on Long Mountain, could be observed on at night, although the atmosphere was very seldom suitable for advancing the triangulation. The latitude observations, completed on the 28th of October, depend on two hundred and twenty-eight results found in fourteen nights with twenty pairs of stars. For value of the micrometer of the zenith-telescope, eighty-two readings were recorded, by observing on two stars. Seventeen nights were occupied in the determination of time with the meridian-telescope by observing on eighty-six stars. The azimuth was ascertained by one hundred and eighty-four pointings on Polaris, on seven nights, the observations being some direct and some reflected in mercury. The measurement of horizontal and vertical angles detained the observers on Long Mountain until the 9th of December. In addition to the series of exact angular measures recorded for the triangulation, Assistant Mosman in the course of the season observed on twenty-four subsidiary objects, mostly prominent mountain-peaks, churches, court-houses, &c., and besides recording their direction from the several stations which he occupied, determined the height of the subsidiary points by vertical angles. The statistics of the main triangulation are:

Stations occupied	3
Angles measured	11
Number of observations	2, 978

For ascertaining the height of primary stations above the level of the sea, zenith-distances were measured with the vertical circle, and upward of two thousand observations were thus recorded.

Assistant Mosman was aided in the field and in office-work by Mr. W. B. Fairfield, and by Mr. D. S. Wolcott until the 12th of December. During part of the summer Mr. C. L. Gardner was attached to the party. The computations resulting from the triangulation were completed in the course of the spring of the present year. After turning in the records Mr. Mosman again took the field and is now pushing the triangulation across the southern boundary of Virginia, in a pre-arranged direction for joining properly with the southern part of the series of quadrilaterals, of which mention will be made further on in this report, under the head of Section V.

Reconnaissance for triangulation in Virginia.—After the return of Subassistant Edwin Smith from Chatham Island, in the South Pacific Ocean, to which place he had been assigned with a party for observing the transit of Venus, in December, 1874, and when the records of that work were complete, preparation was made for resuming his usual field-duties. Late in July, 1875, Mr. Smith commenced reconnaissance for stations to be occupied by Assistant Mosman to the southward of Lynchburg, and in doing so kept in view the necessity of selecting a course the most direct for joining with the chain of triangles which has been pushed north and east from the base-line near Atlanta, Ga. Following, in general, along the eastern flank of the Blue Ridge, a scheme for the main triangulation was laid out by Mr. Smith. This proved to be entirely acceptable, and the junction in North Carolina with the southern part of the same chain of triangles is satisfactory. The party in reconnaissance kept the field until the 3d of November. As he passed from station to station Mr. Smith made arrangements at several for subsequent occupation by Assistant Mosman.

Subassistant Smith was engaged during part of the present year in Section IV.

Mr. A. H. Scott, after his return at the end of June, 1875, from Chatham Island, in the South Pacific Ocean, where he had been on duty with the party sent to observe the transit of Venus, was

engaged, until the end of the year, in comparing with the standard the brass meters which had been constructed in the office. He made at the same time abstracts and reductions of all the recorded comparisons of the committee meter, and of the iron and steel meters, all of which are used in the final tests of the length-measures issued from the office.

Early in March, Mr. Scott had completed computations for the latitude of the station on Chatham Island at which the transit of Venus was observed in December, 1874. He then took up, under the direction of Assistant J. E. Hilgard, the computation of results from the record of magnetic observations which had been made within the year. These in graphical form, together with others, are incorporated in the illustration to Appendix No. 21, which accompanies this report.

In the latter part of the fiscal year Mr. Scott arranged the details and made an inventory of metric weights and measures and comparisons of the British yard-measures.

Reconnaissance in West Virginia.—The examination of the mountain region of West Virginia with reference to points for primary triangulation was continued during the summer of 1875 by Assistant S. C. McCorkle. West of the Gauley Mountains the country as far as the Ohio presents a succession of peaks and very short ridges, having an average and nearly equal elevation of about seven hundred feet. Hilly as the region is, it presents few natural facilities for the purpose desired, the lines of sight being generally too short for conformity with the character of the triangulation already completed to the eastward of Gauley River.

While this work was in progress the details of field-work in Northern Georgia required the recall of Mr. McCorkle for additional points there, the triangulation-party in Section VII having occupied all the practicable points that had been selected in previous reconnaissance to the westward of the Atlanta base-line. The reconnaissance in West Virginia will be completed early in the present fiscal year.

SECTION IV.

ATLANTIC COAST AND SOUNDS OF NORTH CAROLINA, INCLUDING SEAPORTS AND RIVERS.
(SKETCH NO. 9.)

Hydrography of Pamplico Sound, N. C.—This work has been further advanced by a party in charge of Lieut. Richard Wainwright, U. S. N., assistant in the Coast Survey, with the steamer Arago. The part sounded between the 20th of December, 1875, and the 10th of May following includes most of the interval between Gibb's Point and Stumpy Point and the middle of Pamplico Sound southward and eastward of Long Shoal Point. Before the work in this quarter had been extended eastward across the sound, the party in the Arago was transferred to Alligator River, a survey of which, beyond the limits previously reached, was requested in the interest of public improvements. Lieutenant Wainwright promptly took in hand the river-survey and traced the shore-lines southward as far as Blunt's Canal. The channel was subsequently sounded by the party and the vicinity mapped on a scale sufficient for the public uses in view when the survey was requested. Lieutenant Wainwright was assisted in this section by W. P. Ray, Master, U. S. N., and by Ensign F. H. Lefavor. Seventeen signals were erected in the course of the season. The general statistics of the work are:

Miles run in sounding	800
Angles measured	4, 517
Number of soundings	35, 663

Earlier in the fiscal year Lieutenant Wainwright conducted hydrographic work on the coast of Texas, as will be stated under Section IX.

Latitude and azimuth at Roanoke Island, N. C.—With a view of having determinations of latitude and azimuth at several stations in this section, Subassistant Edwin Smith was sent in December, 1875, with a party in the schooner Dana to observe at certain of the stations which had been occupied for the triangulation of Pamplico Sound and the adjacent waters. Bad weather and contrary winds delayed the arrival of the vessel until the 13th of January, when the Dana anchored in Oyster Creek, near Sand Island Station, which is near the southeast end of Roanoke Island.

Only a small part of the ground near the station was found to be covered with sand, and that, although the depth of the covering was eighteen inches, yielded sensibly under the pressure of the foot, so that vibrations were sensible at distances of eight or ten feet from the impression. Natural conditions being unfavorable, Subassistant Smith was constrained to put down a foundation of wood and to erect on it a platform for the meridian-instrument.

The azimuth at Sand Island was measured from the cap of the tripod which had been used in closing the triangulation of Pamplico Sound. While azimuth-observations were in progress the instrument was elevated twenty-one feet above the ground-level, a condition not favorable for great accuracy, but in this case unavoidable. Mr. Smith and the aid, Mr. J. B. Baylor, completed measurements for azimuth by the 12th of February, 1876, and recorded in the course of the work, for corrections of the sidereal chronometer, fifty-six observations on twenty-two stars with the meridian-telescope No. 13.

Latitude was determined at Sand Island Station from sixty-eight observations recorded on six favorable nights on fifteen pairs of stars. Eighty observations were made for ascertaining the value of the micrometer.

The direction of the azimuth-mark was found from eighteen sets of observations on Polaris, and the angle so determined was referred to the line passing from the observing station to the south end of the Bodie's Island base-line by thirteen sets of measurements of the horizontal angle. The records of the astronomical work, original and duplicate, contained in eight volumes, have been received at the office with the field-reductions.

Magnetic observations.—While the work noticed under the preceding head was in progress, Mr. Baylor recorded at Sand Island a complete set of observations for determining the magnetic declination, dip, and horizontal force.

Means not being available for continuing the operations of the astronomical party in this section, the schooner Dana was dispatched for Norfolk in the middle of February. Subassistant Smith and Mr. Baylor then repaired to the office and took up the computations for latitude and azimuth.

Hydrography of Core Sound, N. C.—For this work, Lieut. J. M. Grimes, U. S. N., assistant in the Coast Survey, with his party in the steamer Fathomer, reached Beaufort, N. C., on the 26th of November, 1875. The projection for the hydrography took in the west end of Core Island, and joining with work done in a previous season, extended southward to include Harbor Island Bar.

After establishing a tide-gauge in the straits, soundings were advanced by working eastward. Some of the ground-marks set when the triangulation was prosecuted had been lost by the washing away of the shore, but a sufficient number remained of points subsequently marked by the plane-table party for service in the hydrography.

Lieutenant Grimes noticed that during calm weather the rise and fall of tides in the sound was regular, as also with the wind southward or eastward; but that the tides became very irregular with the wind in any other direction. "A northeast wind, or any wind from northwest to northeast, raises the water in the sound to any height from two inches to two feet. On the contrary, any wind from south-southwest to west drives the water out the sound and lowers the water-level as much as two feet, according to the strength of the wind." In the course of the season in this section the hydrographic party set up thirty-four signals additional to field-points, which had been identified for use in soundings. The general statistics of the work are:

Miles run in sounding	526
Angles measured	4,843
Number of soundings	38,296

Having completed the hydrography of Core Sound, Lieutenant Grimes sailed from Beaufort on the 28th of May, and proceeded with the vessel to Philadelphia. He was aided in the work in Core Sound by Master T. G. C. Salter and Ensign O. W. Lowry, U. S. N.

SECTION V.

ATLANTIC COAST AND SEA-WATER CHANNELS OF SOUTH CAROLINA AND GEORGIA, INCLUDING SOUNDS, HARBORS, AND RIVERS.—(SKETCH No. 12.)

Hydrography of Winyah Bay and its approaches, S. C.—For this work two sheets were projected, one to show the soundings on Georgetown Bar and at the entrance, the second to represent the hydrography of Winyah Bay and the mouths of the Pedee, Waccamaw, and Sampit Rivers, at the head of the bay. Both sheets have been completed by Lieut. C. T. Hutchins, U. S. N., assistant in the Coast Survey, with his party in the steamer Endeavor. That vessel left New York for this section on the 25th of October, 1875, and returned to port at the end of May of the present year.

For the hydrographic survey of Winyah Bay, forty-six signals were set up and determined in position by occupying thirty-five stations on the shores. In the course of the season the tides were observed at four stations, and an aggregate of nearly seven thousand observations were recorded from the tide-staff. Currents were observed in Bottle Channel (Georgetown Bar), and at the entrance to the main channel; also at three stations in Winyah Bay. Specimens of bottom found in soundings were taken at each of the current-stations. Three wrecks were determined in position and twelve buoys, and these with other customary details appear on the hydrographic sheets. Masters S. H. May and W. M. Wood, U. S. N., were attached to the party in the Endeavor at the outset of the season. The last-named officer was transferred to another section in January and was detached from Coast Survey service in March. Lieutenant Hutchins was aided in this section by Ensign H. McCrea. The hydrographic statistics are:

Miles run in sounding	492
Angles measured	2,627
Number of soundings	25,453

Under Section II reference has been made to work previously done by the party in the steamer Endeavor.

Hydrography of North Edisto and South Edisto Rivers, S. C.—For the purpose of sounding the sea-water channels that bound Edisto Island, and which form an important link of the inland navigation along the southern coast, Lieut. J. F. Moser, U. S. N., assistant in the Coast Survey, took the schooner G. M. Bache into the South Edisto on the 11th of April, after the completion of hydrographic work at a point which will be mentioned under the next head. Without delay a tide-staff was set up at East Landing, another in North Edisto River, and search was made for station-marks on which to base the hydrography. Stone posts had been buried out of sight some years ago at the triangulation-points, but as found from time to time by the colored inhabitants they were removed and put to use as anchors for their boats. Houses, too, marked on the hydrographic projection had been so completely carried away that their sites could not be identified. At the east end of the Edisto base-line the monument had been turned over by ignorant people in search for a supposed treasure, and no trace remained of the side-posts at the west end of the base. Fortunately, the monument at that end had not been disturbed, and was made available by Lieutenant Moser for adjusting the hydrographic work in South Edisto River. That stream was sounded upward to its connection with the Dawho. Saint Pierre Creek was sounded, the upper part of North Edisto, Dawho River and its branches, and each of the creeks passable for boats on Edisto Island. Lieutenant Moser states that the shoals that form in the middle of the rivers are invariably of hard sand, the banks at the same places being soft mud. The statistics of work are:

Miles run in soundings	252
Angles measured	1,738
Number of soundings	22,477

Hydrography of Saint Helena Sound, S. C.—Remarkable shore-line changes caused by sea-encroachment at the north end of Hunting Island were mentioned in my report of last year. In order to ascertain the corresponding alterations in depth, a projection was intrusted to Lieutenant

Moser, who reached the locality in the schooner G. M. Bache on the 21st of February, 1876. As soon as possible a few points were determined additional to those marked on the projection, and the altered shore-line was traced by the hydrographic party.

The new channel passing the north end of Hunting Island and leading into Johnson's Creek is reported by Lieutenant Moser as having eight feet at mean low water. A line of soundings was run through midchannel in Harbor River as a means for determining whether or not any alteration had been caused in the depth of that entrance. The tides were observed and recorded for one lunation at the light-house wharf, Hunting Island. In the new channel current-observations were tried, but Lieutenant Moser found that there the current was mainly induced by the wind. To his inquiries in regard to the probable rate of encroachment the replies given by the nearest residents were not consistent. It was, however, observed by the party that at one place on the exposed side thirteen feet of the bank washed away in the course of six weeks. The rate of sea-encroachments has seemed to depend on the frequency and violence of easterly storms, but is now so much lessened that comparison of the outline traced early in July, 1875, with that found in March last by Lieutenant Moser shows very little alteration corresponding to that interval of time. The statistics of the hydrographic work are:

Miles run in soundings	65
Angles measured	758
Number of soundings	7,543

Lieutenant Moser was assisted in this section by Master J. B. Murdock, U. S. N. After completing the work mentioned under the preceding head, the schooner was returned to Baltimore, and was there refitted for service in Section II.

Primary triangulation.—Assistant C. O. Boutelle during the course of the fiscal year occupied and completed observations at five primary stations in the mountain region of South Carolina and Georgia. Of these the most southern station was occupied first. After completing the measurement of angles at Blood Mountain and Rabun in Northern Georgia, the primary points at Pinnacle, Paris, and Mauldin, S. C., were occupied in succession, field-work for the season closing at the stations last named late in December, 1875.

The several stations mentioned above are part of the series of points selected in reconnaissance for a chain of quadrilaterals stretching northward and eastward from the base-line near Atlanta, and to be ultimately joined with a series of quadrilaterals which has been extended southward and westward along the Blue Ridge through the State of Virginia. (See sketches Nos. 10 and 11.) Blood Mountain, 4,468 feet high, was occupied by Mr. Boutelle late in June, and the measurement of horizontal angles with a 20-inch theodolite was completed by the 15th of July, 1875. Seven primary stations were observed on from Blood Mountain, and the approximate positions and elevations of twenty-three subsidiary points were noted in a separate record.

In the middle of July the party was transferred to Rabun Mountain, where observations were begun on the 27th of July. This station has a height of 4,717 feet, and is nearly forty miles distant from Blood Mountain. On reaching the station at Rabun it was found that the large signal-pole previously set up in the reconnaissance had been shattered by lightning, and that the signal left at Blood Mountain had disappeared. Subsequently, it was ascertained that two days after the party left Blood Mountain the signal-pole there had been totally destroyed by lightning, making the third instance which had occurred in the operations of this party in the course of two months The theodolite at Rabun Mountain was protected as far as practicable by the erection of a lightning-rod, which was transferred after the 13th of August, when the party was moved. Twenty-one prominent mountains and other objects were observed on from Rabun, exclusive of eight primary signals on which the measurements were repeated, as usual, with the utmost accuracy.

Pinnacle Mountain, 3,442 feet high, in South Carolina, was occupied, and while arrangements were in progress for adjusting the theodolite there, Mr. Boutelle found it practicable to establish a tripod-signal on Wofford College, in Spartanburg. Having adjusted a structure for subsequent use on the college building, observations were begun at Pinnacle on the 25th of August, and were completed on the 8th of September. Six outlying signals were observed on, and thirty-six mountain-

peaks or other subsidiary objects, notes of which in respect of direction, though made incidentally, will be of special value hereafter for correcting the State map, or in time for the uses of the State authorities if a survey of the State should be instituted by them.

Favored thus far by good weather, corresponding progress had been made by the party when the theodolite was moved to Paris Mountain, 2,057 feet in height, and about eight miles north of Greenville, S. C. After the middle of September, however, alternating storms, and the smoky or hazy weather of autumn succeeded, and much retarded the observations at this important station. Eleven outlying signals were to be observed on, and three of them were more than sixty miles distant from the theodolite. While the geodetic work was delayed, astronomical observations were recorded for latitude and time with zenith-telescope No. 5 and transit No. 11, by Messrs. H. W. Blair and J. B. Boutelle, aids in the party. Forty-four pairs of stars were used for determining the latitude, each pair being observed on not less than five nights. In reference to the result, Assistant Boutelle remarks:

"Each observer computed the apparent place of the stars he observed, and made the field-reduction of his observations while keeping up with his field-duties. Paris Mountain is nearer the mass of mountains of North Carolina and Tennessee than any other astronomical station is in relation to similar masses. But the resulting latitude is 2″.5 greater than the geodetic latitude brought forward from the mean of four astronomical stations southwest of it, and farther from the mountain masses, indicating attraction of the plumb-line in an opposite direction, or toward tide-water, precisely as was found in Maryland and Virginia."

While operations were in progress at Paris Mountain, Subassistant Edwin Smith was pushing a reconnaissance across the southern boundary of Virginia for stations to connect properly with the triangulation of Mr. Boutelle. To insure the conditions desired the two observers conferred at Paris Mountain in October, and the entire scheme was soon after perfected.

At the geodetic station near Greenville azimuth was determined by observations recorded on twelve nights between October 23 and November 20, 1875. Owing to frequent intervals of bad weather the measurement of horizontal angles was not concluded until the 1st of December. Exceptionally good weather returning some days after, Mauldin station was occupied with the theodolite, and the horizontal angles at that center were measured between the 8th and 14th of December. Before leaving the field at either of the stations, the point of observation was securely marked for identification at any time hereafter. The statistics of the triangulation of this year are:

Stations occupied	5
Angles measured	33
Number of observations	2,867

Mr. Blair, when detached from the party of Assistant Boutelle, reported at the office in Washington, and during the winter tested the graduation of several of the theodolites that had been in use, and also the capacity of the dividing engine to repeat precisely in consecutive subdivisions of the same limb. During the remaining part of the fiscal year Mr. Blair was engaged in arranging matter for the publication of the transatlantic longitude work of the year 1872. At intervals, however, he was employed in making the comparisons needful for the adjustment of length-measures (meters) constructed in the office, and in computing star-places for use in future observations.

Tidal observations.—The need of a full series of tidal observations at some point on the Atlantic coast of the Southern States having been long pending, provision has been made for recording a series either at Port Royal, S. C., or at Fernandina, Fla. As the selection of the station could not be definitely made previous to the coming winter, the apparatus intended for it, and in which are combined all the later improvements for registering the tidal action continuously, was sent to the National Exhibition at Philadelphia, and there remained during the summer of the present year as one of the objects in the collection which made up the Coast Survey exhibit in the Centennial Exposition.

SECTION VI.

ATLANTIC AND GULF COAST OF THE FLORIDA PENINSULA, INCLUDING THE REEFS AND KEYS AND THE SEAPORTS AND RIVERS.—(SKETCHES NOS. 13*a*, 13*b*, AND 14.)

Hydrography of Fernandina Harbor, Fla.—For the purpose of facilitating the action of the Engineer Department, when questions in regard to the improvement of the entrance channels were under consideration, a hydrographic survey of the bar of Fernandina Harbor was directed in November, 1875. The work was begun on the 1st of December, and was prosecuted till the 3d of January following by Lieut. Commander J. C. Kennett, U. S. N., assistant in the Coast Survey, with his party, in the steamer Bache.

"Careful attention was given to the development of known and probable channels. Well-marked shoals and breakers and the deepest water, as shown by previous surveys, were not examined. Our work will, I think, show no decided change, except the gradual movement of the main channel to the southward."

Lieutenant-Commander Kennett traced the altered shore-line of Cumberland Island, and marked the results on his hydrographic sheet. The statistics of soundings are:

Miles run	120
Angles measured	1, 024
Number of soundings	10, 056

For purposes of comparison, tracings from the sheets of the last and preceding surveys were furnished to the Engineer Department.

Lieutenant-Commander Kennett was aided in this section and also in Section I by Acting Ensign George Glass.

Survey of the Saint John's River, Fla.—To provide for extending the survey of the Saint John's River above Jacksonville, a party was organized under the charge of Assistant H. G. Ogden for service with the steamer Hitchcock, and that vessel was dispatched from Baltimore on the 24th of October, 1875. Except between Cape Fear and Saint Helena the southern passage was made entirely through the inland waters. The steamer reached Jacksonville on the 12th of November. Without delay search was made for points at which the triangulation of the river had ceased when the survey in a former year was closed near Jacksonville. From thence to the southward a reconnaissance was conducted by Assistant Ogden to Enterprise on Lake Monroe, which is a hundred and fifty miles by the river-course to the southward of Jacksonville.

On the 1st of January, 1876, the survey of the river was taken up at limits where the work terminated some years ago. A base-line was marked out near Jacksonville, and was carefully measured, and from that vicinity a series of triangles was extended to Mandarin Point. This includes about fourteen miles of the course of the river. Azimuth was measured at the station Bluff, by forty-eight observations on Polaris near western elongation, on three different nights. The shores of the river were traced by means of the plane-table within the limits of the triangulation, but the funds available for the operations of this party did not admit of extending the hydrography above Jacksonville. Tidal observations, however, were made during one lunation. In the reconnaissance soundings were carried throughout as far as Lake Monroe. Mr. Ogden reports that the channel of the Saint John's has nine feet of water as far as Buchalou's Bluff, which is nearly eleven miles south of Pilatka, and from thence on a depth of seven feet to Volusia Bar at the southern end of Lake George. The depth on that bar is only four and a half feet, but to the southward, and as far as Lake Monroe, the channel has an average depth of seven feet. A bar, however, is met where the river passes into the last-named lake. The capacity of the channel as here mentioned refers to an average stage of the river. During freshets the depths are increased by several feet, but at the lowest stages the water is seldom as much as one foot less than the depths here reported.

Subassistant W. I. Vinal was attached to the party in the steamer Hitchcock, and Messrs. F. H. North and J. F. Pratt served as aids. Field-work was prosecuted until the 1st of April, when the

vessel was laid up at a station in the river, about two miles above Jacksonville, in readiness for resuming the survey hereafter. The following are statistics of the survey as far as it was advanced:

Signals erected	19
Stations occupied	19
Angles measured	148
Number of observations	4,458
Shore-line surveyed, miles	36½
Roads, miles	12
Topography, square miles	4
Miles run, reconnaissance	204
Casts of the lead	7,104

Twenty-four points were determined in position by the triangulation of this year on the Saint John's.

Survey of Indian River, Fla.—In continuation of this work, Assistant Charles Hosmer organized a party and resumed operations on the 4th of October, 1875, in the upper part of Indian River, where he had closed work at the end of May of the same year. Of the several branches of survey the triangulation was pushed to the southward twenty-six miles, and the topography nearly twenty miles. Soundings were completed within the plane-table limits.

The country over which the work of this season extends is similar to that passed over last year, except that the west side of Indian River, south of Titusville, is dry and sandy, and covered with a dense growth of pine, palmetto, and oak. The west bank is about ten feet above high water at Titusville and gradually attains a height of eighty to one hundred feet in the vicinity of City Point and Oleander Point. The region is very sparsely inhabited and means of communication are yet wanting.

Banana Creek, a branch of Indian River above Cape Canaveral, was included in the survey of this year. The sloop Steadfast was used in this work while means held out for prosecuting the survey, but in the middle of February of the present year the vessel was laid up and the party disbanded.

Assistant Hosmer was aided in the field by Subassistant Eugene Ellicott and by Messrs. W. E. McClintock and T. A. Harrison. As yet the detailed survey of the outer coast rests at a point several miles north of Cape Canaveral, but the survey of Indian River has been extended as far to the southward of the Cape. The statistics of this season are:

Signals erected	23
Stations occupied	23
Angles measured	467
Number of observations	2,802
Shore-line surveyed, miles	186
Roads, miles	29
Area of topography, square miles	100
Miles run in sounding	579
Angles	1,962
Casts of the lead	20,900

Twenty-six points were determined in position by observations with the theodolite.

Hydrography of Key Biscayne Bay, Fla.—Under the head of Section II, in this report, mention has been made of the associate service of Lieut. C. A. Bradbury, U. S. N., assistant in the Coast Survey, on board the schooner Palinurus, and of the transfer of that vessel to his charge in December, 1875. The schooner was refitted at Norfolk and reached Charleston, S. C., on the 27th of January. Frequent storms delayed the passage of the party southward. Off the coast of Florida the damage sustained by the vessel made it necessary to return to Saint Augustine for repairs. The Palinurus reached Cape Florida on the 19th of March and next day passed up to the head of Key Biscayne Bay. Lieutenant Bradbury set up a tide-staff at the mouth of Miami River, and identified the ground-marks, which were set in 1855 at the ends of the base-line measured on the shore of the bay. Twenty-two signals were set up, and triangulation was carried from the light-house at Cape Florida

so as to connect with the north end of the Key Biscayne base. As soon as practicable, soundings were commenced in the bay, and by the 13th of May the hydrography was completed up to the mouth of the Miami. The statistics of this work are:

Miles run in sounding	172
Angles measured	1,152
Number of soundings	15,263

Lieutenant Bradbury with his party in the Palinurus left Key Biscayne Bay on the 16th of May and passing southward recorded notes for compilation in the Coast Pilot of the Florida Reefs. Sailing-lines were run for the Hawk Channel; and for entering Key West Harbor; also for crossing the reefs at Knight's Key, Indian Key, and abreast of the Ragged Keys. Between Virginia Key and Key West all the harbor-approaches and the appearance of the land in their vicinity were noted for compilation, and the outside sailing-lines were traced from Cape Florida to the Tortugas. This service employed the vessel until the middle of June, when the party was recalled. Lieutenant Bradbury then returned to New York and laid up the vessel.

In the middle of April, while Lieutenant Bradbury was with his vessel at Miami in Key Biscayne Bay, he was requested by the United States district attorney for the southern district of Florida to assist in arresting three men for whom warrants had been issued on a charge of murder. After the same request had been urged by the deputy United States marshal the persons charged were arrested, and for security were kept by Lieutenant Bradbury on board the Palinurus until the schooner Liberty, which had been sent from Key West by the district attorney, was ready to transfer the prisoners to that port.

Triangulation of Sarasota Bay, Fla.—After the completion of work which will be mentioned under the next head, Subassistant Joseph Hergesheimer transferred his party in February of the present year in the schooner Speedwell to Sarasota Bay and selected stations for a triangulation to extend above and below Long Boat Inlet. Several lines of sight were opened through the growth of pine and mangrove that abounds along the shores, but the limited means available for the work of this party did not admit of occupying either of the stations with the theodolite. A good harbor is found inside Long Boat Inlet with nine feet of water on the bar. Mr. Hergesheimer reports that between that inlet and Tampa Bay the channel has five and a half feet at low water, and that the depth is greater to the southward. Several inlets, moreover, with good water on the bars, will doubtless be developed when the work is extended to the lower part of Sarasota Bay. Subassistant Hergesheimer was aided in this section by Mr. Charles Tappan. The work was discontinued for the season on the 1st of March, but arrangements are now in progress for pushing the triangulation and shore-line survey during the ensuing winter.

Topography of Hillsboro' Bay, Fla.—The party of Subassistant Hergesheimer was in readiness in this section before the close of November, 1875, with the schooner Speedwell, but owing to the inclemency of the weather plane-table work was prevented until the 10th of December, 1875. At all favorable intervals Mr. Hergesheimer took the field, and by the end of January had mapped the shores of Hillsboro' Bay, essentially completing the survey of Tampa Bay and the adjacent waters. The statistics of the work are:

Shore-line surveyed, miles	110½
Roads, miles	21½

Mr. Tappan served as aid. Work subsequently done by this party has been noticed under the preceding head.

Hydrography of the Gulf coast near Sarasota Bay, Fla.—After completing in March the hydrography of Hillsboro' Bay, mention of which will be made in its proper geographical order under the next head, Lieut. J. M. Hawley, U. S. N., assistant in the Coast Survey, with a party in the schooner Earnest, took up soundings outside of Long Key, which in part separates the waters of the Gulf of Mexico from Sarasota Bay. Above Long Boat Inlet a junction was made with the hydrographic work done in a previous season by Acting Master Robert Platt, U. S. N., and from that limit the hydrography was extended southward to New Pass. Seaward the lines of soundings were carried about five miles through the waters of the Gulf. Signals were set up along the shore of the Key

by the middle of April. The boisterous weather which prevailed until the 17th of May, when the work was closed, made it impracticable to employ the launch. At intervals when the water was not too rough the Earnest left her anchorage in Sarasota Bay and added to the record of soundings.

"The only available pass, for vessels drawing over five feet, into Sarasota Bay, is Big Sarasota Pass, and that is dangerous in bad weather. Long Boat Inlet is sometimes used in fine weather."

In addition to the hydrographic sheet of Gulf soundings, Lieutenant Hawley has turned in a sheet on a large scale, showing the character of Long Boat Inlet. The statistics of his work in the vicinity of Sarasota Bay are:

Miles run in sounding	173
Angles measured	509
Number of soundings	2,647

Work was closed for the season in this section by Lieutenant Hawley on the 18th of May, when the schooner Earnest returned to the North, and, after refitting at Boston, was employed for service in Section I.

Lieut. U. R. Harris, Master G. C. Hanus, and Ensign A. H. Cobb, U. S. N., assisted in the Gulf hydrography mentioned under this and the next head. Previously, the party had been employed in work which has been noticed under the head of Section I.

Hydrography of Hillsboro' Bay, Fla.—Lieutenant Hawley, having turned over the command of the schooner G. M. Bache to Lieut. J. F. Moser, took charge of the schooner Earnest, and sailed from Baltimore on the 17th of December, 1875. Continued rough weather off Cape Hatteras made it expedient to return to Hampton Roads, from which, after needful repairs, the vessel was passed through the Albemarle and Chesapeake Canal and again put to sea through Ocracoke Inlet, meeting there a favorable wind on the 11th of January. At Key West, coal was shipped for use in the small steam-launch assigned for service in the hydrography. The schooner reached Tampa on the 9th of February. Signals were set up immediately, and soundings were begun in Hillsboro Bay. The steam-launch arrived on the 15th, and two days after was in effective service, with a sounding-party on board. At the outset, Lieutenant Hawley established a tide-station at Tampa, where day and night observations were recorded during forty days. All intervals of weather favorable for work were occupied by the two parties in advancing the hydrography of Hillsboro' Bay, which work was completed by the middle of March.

"The soundings in Hillsboro' Bay develop a good two-fathom channel to within about two miles of Tampa, where the bottom gradually rises and becomes bare at low water, except in the narrow, tortuous channel, through which only six feet can be carried at mean low tide into Hillsboro' River.

"The shoals in the bay are all of hard sand; the bottom of the channel is everywhere of soft mud, and hence in going up the bay soft bottom is an indication of being in the best water. Anchorage is good about a mile to the northward of Ballast Point for vessels drawing less than ten feet."

The statistics of work in Hillsboro' Bay are:

Miles run in sounding	363
Angles measured	1,414
Number of soundings	21,103

Subsequent work done by the party of Lieutenant Hawley in this section has been noticed under the preceding head.

SECTION VII.

GULF COAST AND SOUNDS OF WESTERN FLORIDA, INCLUDING THE PORTS AND RIVERS.

(SKETCH No. 15.)

Topography and hydrography north of Cedar Keys, Fla.—After the completion of duty which has been noticed in this report under the head of Section III, Assistant F. W. Perkins organized a part for service with the schooner Ready and left Old Point Comfort on the 11th of January, 1876

Light winds and calms delayed the passage, but the party was at work near Cedar Keys by the end of that month. The triangulation requisite was pushed from Bowlegs Point southward by occupying stations near the shore-line of the Gulf and observing with the theodolite on signals placed several miles out in the Gulf waters. In March a base-line was measured 3335.7 meters long on the coast south of Bowlegs Point.

Following the triangulation the plane-table survey was advanced from Bowlegs Point southward and eastward as far as Horse-shoe Bay. The shore-line survey was continued in the same direction to the mouth of Suwanee River. This part of the coast is skirted with many small islands and is marked by well-defined reefs running parallel with the shore-line.

Within the limits of the completed topography soundings were made, the lines generally running out to an average distance of about eleven miles from the Gulf coast. The statistics of the work are:

Signals erected	41
Stations occupied	8
Number of observations	2, 471

Twenty-four points were determined by the triangulation.

Shore-line surveyed, miles	63
Creek-line, miles	52
Roads, miles	5
Area of topography, square miles	30
Miles run in sounding	557
Angles measured	2, 440
Number of soundings	30, 707

Field-work was discontinued early in June. The schooner Ready was soon afterward laid up at Apalachicola, where preparations are now in progress for resuming the survey near the mouth of Suwanee River. Messrs. J. De Wolf and W. S. Bond were in service with the party in this section.

Hydrography of Appalachee Bay, Fla.—For resuming work in this section the party of Master Kossuth Niles, U. S. N., Assistant in the Coast Survey, was reorganized at Saint Mark's on the 23d of October, 1875, the schooner Silliman having been previously laid up in Apalachicola River. In the course of a week, day and night observations were commenced with two tide-gauges at Saint Mark's light-house and the record was continued during the month of November. Five sheets had been projected at the office, to include the hydrography of the Gulf coast from Rock Island westward to Turkey Point, taking in Appalachee Bay and its several tributaries, among which are Ocilla River, Stony Bayou, Saint Mark's River, West Bay, Shallow Bay, Ocklockony Bay, and farther to the westward, Alligator Harbor. These were all developed by soundings in the course of the season. During the winter the weather was very unfavorable for service afloat. Near the end of February, when the weather somewhat improved, Master Niles was joined by a steam-launch which had been provided to aid in the hydrography, and good progress was made in the work until the 19th of March, when operations on this part of the coast were interrupted by a very heavy gale, which blew down some of the signals relied on for continuing the soundings. By the 29th of April all the hydrography intended to the eastward of South West Cape was completed. For reducing the soundings afterward made to the westward of the cape, a tide-gauge was established at the wharf at Saint Teresa, and a plane of reference obtained for it from day and night observations during two weeks. Launch and gig being both kept at work during a favorable period, the fourth hydrographic sheet was finished on the 23d of May. The interval between that date and the 1st of June was occupied in making supplementary soundings in Saint Joseph's Bay, north. Master Niles took up the general hydrography of Appalachee Bay on the 9th of June. As the signals could not be seen beyond the outer limit of the work already executed, Master Niles detailed an officer from the schooner to occupy the light-house with a theodolite, and anchored the Silliman in positions most advantageous for the hydrographic work. The vessel was held by a short stay with mainsail up, and on signal from the launch simultaneous observations were recorded on the launch from the light-house and from the mast-head of the schooner. At the same time an observer on the

launch measured the angle made by imaginary lines to the vessel and the light-house or other available object. The fifth sheet of soundings was completed on the 26th of June. A few days after, the schooner and launch were laid up in Saul's Creek above Apalachicola. After discharging the crew, Master Niles, assisted by Masters W. F. Low, H. O. Rittenhouse, and H. W. Schaefer, U. S. N., completed the charts resulting from the work of the season, and forwarded them to the office with duplicate records of the soundings and tidal observations. The statistics are:

Miles run in sounding	1, 352
Angles measured	7, 662
Number of soundings	109, 985

Master Niles is now engaged in hydrographic work in Section VIII.

Near West Pass, on the 25th of May, when Master Niles was on his course for hydrographic work in Saint Joseph's Bay, the Pensacola navy-yard steam-tug Rose was seen aground and to be thumping badly on the East Bank. After taking off the passengers, ten in all, and landing them at Apalachicola, Master Niles returned to the tug, the head of which by the aid of the launch had been previously got to sea, and as the rudder of the tug had been destroyed in the breakers, the vessel was towed to the upper anchorage off Apalachicola.

Gulf hydrography near Pensacola entrance, Fla.—East and west of Pensacola entrance, a stretch of about sixty-five miles of the Gulf coast has been sounded by the party of Lieut. R. D. Hitchcock, U. S. N., assistant in the Coast Survey, working with the steamer Gedney. For that service the vessel left New York on the 5th of November, 1875, but next day, being disabled in machinery, was brought to anchor off Lewes, and as soon as practicable, was repaired at Chester, Pa. Leaving the Delaware, after delay of three weeks in consequence of the accident, the Gedney reached Pensacola on the 7th of December.

The hydrogaphic work done between that date and the end of April, 1876, is comprised on three sheets. Thirty signals were erected and eight stations on shore were occupied in the course of the season. Thirteen buoys within the working-limits were determined in position, and also the places occupied by three wrecks. Generally, the lines of soundings were extended ten miles from the coast into the waters of the Gulf. Upward of fifteen thousand tidal observations were recorded at a station on the wharf at Fort Pickens.

The currents were observed off the outer bar of Pensacola Harbor. Other statistics of the hydrographic work are in the following summary:

Miles run in sounding	548
Angles measured	747
Number of soundings	5, 939

Lieutenant Hitchcock was assisted in this service by Lieut. James Franklin, and by Masters John Hubbard, H. C. T. Nye, and J. L. Hunsicker, U. S. N. The steamer Gedney had been previously employed in Section I.

Geodetic connection, Georgia and Alabama.—When my report of last year closed, the party of Assistant F. P. Webber had completed observations at John's Mountain, a station in Northern Georgia, about twenty-five miles from the boundary-line between that State and Alabama. The instruments were transferred to Indian Mountain in Alabama early in July, 1875, and on twenty-six outlying signals the measurement of horizontal and vertical angles was continued until the 20th of August. Lavender Mountain in Georgia was reoccupied at the same time for a few days by Sub-assistant F. D. Granger to perfect its connection with stations selected to the westward since that station was first occupied by Assistant Webber. (See sketch No. 11.)

Early in September the party was transferred to Gulf Point, and there measurements with the theodolite were completed by the 9th of October. Some delay arose at this station in consequence of the difficulty of identifying the signal at a station somewhat more than forty miles to the westward. Mr. Webber took the field for reconnaissance, and had the co-operation of Assistant S. C. McCorkle, who had selected the stations which make up the scheme of this triangulation. Pending the required modification, Assistant Webber had his party and instruments moved to Brandon Station in Alabama, and by the close of the year completed the angular measurements requisite at

that point in the series. In the first week of January the camp-equipments were stored at Marietta. Mr. Webber and Subassistant Granger then took up the computations, and after completing them and duplicating the records forwarded the data as usual for deposit in the office. The general statistics of the triangulation are:

Stations occupied	4
Angles measured	78
Number of observations	1,980

From the four primary stations vertical angles were measured on seventy-six outlying points, principally mountain-tops or well-recognized hills.

Assistant Webber was aided in the field by Mr. J. H. Christian.

In extending reconnaissance to the westward for continuing the triangulation here noticed, natural difficulties interposed. Stations in the direction and at the distance required were hid from view by intervening ridges, all having nearly the same height. Assistant McCorkle made a close examination of the region, and ultimately found stations for a quadrilateral westward of the stations at which angular measurements had been completed by Assistant Webber. As, however, it is known that similar obstacles to progress will interpose in proceeding in the same direction, Mr. Webber has been directed to perfect, by reconnaissance, a scheme for continuing the triangulation westward previous to the completion of angular measurements at the western border of the scheme which now rests near the eastern boundary-line of Northern Alabama.

Triangulation in Kentucky.—In conformity with the request of Prof. N. S. Shaler, director of the State Geological Survey of Kentucky, field-work was commenced by Prof. William Byrd Page near Cumberland Gap, on the 7th of July, 1875, and operations were continued until the 4th of November. The country was examined in a northwesterly direction about sixty miles, toward Livingston. As reported at the end of the season, the movements in reconnaissance were greatly retarded by rains and fog. The mountain-ranges of the region are heavily timbered and the roads bad.

So far as laid out, the scheme for triangulation consists of one quadrilateral and an additional triangle, with sides from twenty to thirty-nine miles in length. The elevations of the principal stations above tide vary from 1,550 to 3,465 feet.

Within the limits of the scheme two sites were examined for a base-line, one in the valley of Yellow Creek, near Cumberland Gap, and the other on the flats near Barbourville, in Knox County. Because of the difficulty of leading by triangulation out of the narrow valley of Cumberland River, the site on Yellow Creek is reported as being somewhat less objectionable, but the difficulties to be encountered in the measurement are such as have not been undertaken elsewhere. Preliminary measurement gave for the length of the line 2.94 miles, and with the usual angular measurements, determined the approximate length of triangle sides. These, when located by Professor Page according to the topography as laid down on the latest existing map of the State, strongly reveal its discrepancies and prove the necessity of the work now in hand.

In all directions from the vicinity in which the reconnaissance was started, the country is reported as favorable for extending the scheme of triangulation. The mountains of North Carolina are plainly visible from some of the stations selected by Professor Page, and points on them will admit of easy geodetic connection in the future.

Field-operations were resumed in Southeastern Kentucky early in June, 1876, and the work is now in progress. The advance made this season will be stated in my next annual report.

SECTION VIII.

GULF COAST AND BAYS OF ALABAMA, AND THE SOUNDS OF MISSISSIPPI AND OF LOUISIANA TO VERMILION BAY, INCLUDING THE PORTS AND RIVERS.—(SKETCH No. 16.)

Hydrography, Gulf of Mexico.—Lieut. Commander C. D. Sigsbee, U. S. N., assistant in the Coast Survey, with his party on board the steamer Blake, after the completion of service which has been noticed under a head of Section I in this report, sailed from New York and arrived at Tampa, Fla., at the end of November, 1875. With ample preparation and outfit for deep-sea soundings, the ves-

sel was started at Tampa entrance and ran westward on a line extending a hundred and seventy miles, the record of soundings terminating in the deep-basin of the Gulf of Mexico. Off Charlotte Harbor, and between that entrance and the Tortugas, similar lines were run; and five lines for the same purpose were extended westward at intervals north of Tampa. On these, which make in the aggregate nearly twelve hundred miles, observations were recorded for temperature at and below the surface of the water. Before leaving the eastern part of the Gulf four lines of soundings, averaging about fifty miles in length, were run in directions normal to the coast between Dog Island and Cape San Blas. At the end of January, Lieutenant-Commander Sigsbee sounded on a line, going about seventy-five miles southward from Southwest Pass, Mississippi delta, and recorded soundings on the return to the same station. West of the delta, a line was extended from Timbalier Island southward into deep water. On the 9th of May, the steamer was started in twenty-five fathoms about six miles off the South Pass, and soundings were continued due south to the Yucatan Bank. Subsequently, soundings were begun near the southeast point of Alacran Shoal and were extended as nearly as possible in a direct line on the course to the Tortugas. This line was completed on the 20th of May. Means not being available for retaining the services of the steamer in this section, Lieutenant-Commander Sigsbee returned with his party to New York.

With the deep-sea soundings previously made in the Gulf of Mexico, the data gathered this season may afford means for developing the main peculiarities of this large body of water. Changes of temperature in relation to the depth of water, and the character of the bottom at varying depths, will at an early day become subjects of investigation.

In the Gulf, soundings were made by Lieutenant-Commander Sigsbee with the line and lead in depths of less than 200 fathoms. Small specimens of bottom were secured with the Stellwagen cup, but for larger specimens taken from greater depths the cylinder devised by Captain Belknap, U. S. N., was used. For deep soundings the wire sounding-machine constructed by Lieutenant-Commander Sigsbee on the principle suggested by Sir William Thomson was employed in the Gulf with invariable success. Its importance in deep-sea work is mentioned in the report as amply illustrated by the effective control of the motion of the reel in paying out the sounding-wire. In depths not greater than 1,000 fathoms a weight of twenty-five to thirty pounds is attached to the wire; but heavier weights, detachable on the bottom, are used for sounding in greater depths.

A water-cup devised by Lieutenant-Commander Sigsbee was used for taking specimens of water at various depths. This is so constructed that stoppages, for any purpose while sounding, do not affect the valves of the cup. At the surface, at the bottom, and at intermediate depths, temperatures were recorded with the Miller-Casella thermometer. The greatest difference in temperature at equal depths was found in sounding between Yucatan and the Tortugas. When practicable, the currents were observed while soundings were in progress.

Lieutenant-Commander Sigsbee was assisted in this work by Lieuts. J. E. Pillsbury and W. O. Sharrer, U. S. N.; by Masters R. G. Peck and M. F. Wright, U. S. N.; and by Ensign W. E. Sewell, U. S. N.

The general statistics of the work are:

Miles run in sounding	2,889
Positions determined	180
Number of soundings	842

Survey of the Mississippi delta.—In conformity with an act of Congress approved March 3, 1875 a special survey of the South Pass and its approaches was made in May, June, and July, following, and carefully-traced copies of the topographical and hydrogrphical sheets and the manuscript data pertaining thereto were furnished to the Engineer Department for special purposes which are specified in the act. The general results of the work were stated in my last annual report. Among details then referred to was the measurement of the flow of water through Cubitt's Gap, an opening in the left bank of the Mississippi, a few miles above the head of South Pass. Through that gap a discharge takes place which formerly passed through the main stream of the river and the outlets below. Hence the gauging of that gap, in connection with similar work in South Pass, became interesting for several reasons. The result found in the summer of 1875 not proving entirely satis-

factory, Assistant H. L. Marindin was instructed to make another gauging with his party in the schooner Research. A general plan for the work was included in my directions to Assistant Henry Mitchell for continuing the physical survey of the delta, which has been decided upon because of the many questions arising out of the difficulties of navigation that have been referred to this office.

Subassistant Braid made a triangulation of the vicinity of Cubitt's Gap and its branches and furnished points for the hydrographic survey. The schooner Research, after a tedious passage from Norfolk, arrived on the 29th of December at Pass à Loutre, and as soon afterward as possible commenced the detailed survey of the Gap.

The determination made, as the result of work done in January and February last, was prosecuted some distance seaward of the crevasse itself so as to avoid irregularities of section and all corrections for diagonal flow. After escaping from the crevasse the stream divides into five shoaled passes between small islands, and in these passes sections and transverse curves of velocity were observed almost simultaneously. The greatest interval between observations in different passes was less than one hour. Summing up the discharges through these five passes, just as they occurred, without correction for tidal slopes, gives for the total discharge between 4 p. m. and 6 p. m. of February 7 of the present year, 448,800,000 cubic feet per hour, or about 5 per cent. less than the smallest amount computed from the data of the previous year.

Of course, no very close agreement between the gaugings of the different seasons can be expected however perfect may be the method employed, unless corrections are introduced reducing the data to the same slope and elevation of water-surface. For such corrections the coefficients had not been determined, and subsequent work in the Southwest Pass was performed with a view to determining these; with what success has yet to be learned, the computation being still in progress. Southwest Pass was chosen as the scene of this work, because considerable variations of slope, due to the tides, could there be found.

In this pass, above the reach of the flood tidal currents, the discharge varies as the tide rises or falls. These variations complete themselves in one day, so that they are conveniently observed, and they disappear once in a fortnight, when the Gulf is tideless, so that we may by careful selection of dates compare *velocities* for different *slopes* in a reach of the river where *section* and *perimeter* remain the same (that is, are corresponding for the moments of observation). Could our observations be sufficiently extended, we should probably be able, in the same reaches of the river, to so group results that turn by turn we should determine variables in pairs, with all else constant.

The work in the Southwest Pass has been referred to only from one point of view; there are, however, many contingent features exclusive of dynamic elements in the proper gauging of this and other passes that are not to be omitted. A resurvey, both topographical and hydrographical, of the delta, is in progress, and as far as means will allow the work will be prosecuted with a view of determining for the same period at least the depth on the bar of each of the passes, and representing them contemporaneously on a chart for navigation.

The following statistics show the work performed by the party at the delta during the season

Triangulation.

Signals erected	21
Angles observed	126
Observations	1,460

Topography.

Miles of shore-line run	26

Physical hydrography.

Soundings	9,387
Angles of position	2,780
Miles sounding-lines	101

Tide-gauges put up	10
Cross-sections for volume	11
Stations occupied on sections	79
Current observations	737
Angles of position	194
Miles of level-lines run	9½
Level-readings	663

Mr. J. B. Weir aided in the operations at Cubitt's Gap, and subsequently conducted the details of a special survey in Section III under the general direction of Assistant Mitchell.

Triangulation and topography at Cubitt's Gap and Southwest Pass, Mississippi delta.—For service in the schooner Bibb, which was recalled from Galveston and repaired at New Orleans, Subassistant Andrew Braid organized a party early in December, 1875, and proceeded at once to Cubitt's Gap. Signals were erected and the triangulation was extended from the Head of the Passes to the Gap to furnish points for the detailed topography and for soundings, which were to be prosecuted by Assistant Marindin. The plane-table limits were not large, but incessant fogs that prevailed retarded the completion of the desired work. After furnishing data sufficient for the hydrography, Subassistant Braid moved his party to Southwest Pass, under directions to co-operate with Assistant Marindin, who was to select sections of the Pass at which both parties were to observe the effect of tides and currents. Each party employed two tide-gauges, and observations on all four were recorded simultaneously with the current-observations during twenty-six consecutive hours. Additional to the work done for the hydrographic survey, Mr. Braid determined several points by triangulation along the shores of Southwest Pass. The statistics of field-work are:

Signals erected	31
Stations occupied	10
Angular measurements	4,110
Shore-line surveyed, miles	32
Area, in square miles	10

Messrs. C. L. Gardner and C. H. Sinclair aided in the work done by the party in the schooner Bibb. Means not being available for continuing the survey as intended in Southwest Pass, the party was discharged at the end of February. The vessel was laid up at Hurricane Harbor, in South Pass.

Triangulation of Barataria Bay, La.—To provide for this and similar work in the same section of the Gulf Coast, the steamer Barataria was constructed at Louisville, Ky., in the autumn of 1875, and was delivered to Assistant W. H. Dennis on the 16th of December. Early in January of the present year, the vessel was fitted out at New Orleans, and by the close of that month was at the intended working-ground in Barataria Bay. Mr. Dennis first selected a site for a base-line on Grand Isle, and in connection with it stations for triangulation across the bay. Six tripod-signals were erected and reconnaissance was continued for extending the triangulation from the vicinity of the base. A preliminary measurement of the line gave for its length 3.65 miles. The eastern end of Grand Isle, which includes the site of the base-line, was mapped to a distance of about six miles.

Subassistant B. A. Colonna was attached to this party, and Messrs. S. N. Ogden and E. B. Pleasants served as aids. The party was in effective operation in the middle of February, when pressing requirements of the service in other quarters made it necessary by reason of the lessened means to recall the Barataria. The party was in consequence disbanded on the 25th of February, and the vessel was laid up for the season at Algiers. Assistant Dennis had been previously employed in Section I.

Tidal observations.—At New Orleans, tidal observations, with a staff-gauge, have been continued by Mr. G. Faust, who notes the height of the water at intervals of six hours, commencing at midnight, the usual daily fluctuations being small, and for that reason disregarded. The level of the river in front of the city is changed eleven or twelve feet by the annual floods. Some approach to regularity of change with the seasons is indicated by the tidal series, which has been maintained since January, 1872. Further extension of the series may be expected to give means for predicting

approximately what the stage of water may be in the Mississippi at any given time in the same season.

Survey of the Mississippi River.—In continuation of the survey of the river above New Orleans, Assistant C. H. Boyd was at his working-ground on the 9th of December, 1875, with the new steamer Baton Rouge, one of two vessels which had been specially planned for service in the section. Mr. Boyd took charge of the vessel at Louisville, Ky., early in November, and completed the equipment and party outfit at New Orleans. The survey of the Mississippi was resumed on the 17th of December, and field-work was steadily prosecuted until the middle of April following, when the hands were discharged and the vessel was laid up at Algiers.

The triangulation of the Mississippi was extended by Mr. Boyd upward from Oakland, one of the stations at which the work terminated on the previous season, and by a system of quadrilaterals, was advanced about forty-five miles to Reserve Plantation, in Saint John's Parish. The usual difficulties met in a flat country were overcome by mounting the theodolite about twenty feet at each station. In the lines of sight projected by the reconnaissance, the numerous buildings and adjacent groves of fruit and shade trees that intervened added much in the labor needful for avoiding damage to valuable private estates, which are commonly separated from each other by timber borders. Some cutting in these was indispensable for lines of sight, but the interest for the survey manifested by the owners and their friendly relations have been such as to prompt them to decline any remuneration for the damage caused on their plantations.

The topography was resumed near Kenner, where the work was closed last year, and by two additional sheets the survey was advanced westward to a point above the Bonnet Carre Crevasse. On both banks the ground is represented in detail, except the part which is now covered by crevasse water. Master Alex. McCracken, U. S. N., was attached to the party in the steamer Baton Rouge, and effectively conducted the hydrography of the Mississippi from the limit previously reached to a point about twenty-three miles above New Orleans. Further progress in soundings was prevented by the acceleration of currents due to the unusually early rise of the river. Even when not sounding, the ablest boat's crew were unable to stem the current of the river. In the middle of March soundings were made through the Bonnet Carre Crevasse, and also for a mile or more in the river near that opening. The greatest depth found in the river within the working-limits of this year was forty fathoms, but some of the lines across the river show no soundings above twelve fathoms.

In prosecuting the triangulation eighteen of the lines required cutting, in order to make the ends intervisible for observing with the theodolite. Fifty-one geographical positions were determined by the angular measurements. The general statistics of the work are:

Signals and scaffolds erected	16
Stations occupied	20
Angles measured	271
Number of observations	4, 404
Shore-line surveyed, miles	55
Roads, miles	506
Canals and levees, miles	69
Area of topography, square miles	86
Miles run in sounding	108
Angles with sextant	925
Number of soundings	2, 900

The currents were observed at ten stations while soundings were in progress, and careful observations of the tides were recorded during the entire season.

Messrs. C. H. Van Orden and Bion Bradbury served as aids. At the close of work the vessel was left in charge of Master McCracken whose co-operation and interest in the service are specially mentioned in the concluding report from the field. The same party is about to be reorganized for continuing the survey of the Mississippi above the limit reached in April last. The Chamber of Commerce of New Orleans, desiring to know how the Bonnet Carre Crevasse had affected Lake Pontchartrain, Mr. Boyd waited a week at New Orleans after the discharge of his own party for

want of means for keeping the field, and in hope that means of transportation might be provided by the city. Timely efforts to that end not being successful, Assistant Boyd reluctantly notified the chamber of his inability to meet their wish without a small vessel and working-crew, and at the end of April passed on to report at Washington City.

Triangulation in Wisconsin.—This work has been systematically laid out, and, as far as means would allow, has been successfully prosecuted by Prof. John E. Davies. The base-line marked out in Spring Green Valley between Prairie du Chien and Madison, after conference with Assistant R. D. Cutts, has been measured and found to be approximately 4,624.37 meters in length. The ends were secured by stone posts as usual. Hereafter, the precise distance between marks on the two posts will be determined by a final measurement with apparatus devised for the purpose. From the vicinity of the base the triangulation was laid out to proceed eastwardly so as to connect as soon as possible with the astronomical station at Madison, the longitude of which was carefully determined several years ago by the telegraphic method. With that point included, the determination of azimuth adjusts the scheme of triangles in its true geographical position, and so far the work has been advanced by Professor Davies. In reference to the plan and details of field-work, Assistant Cutts remarks, after a personal examination: "All the figures are quadrilaterals and well conditioned. The exactness of the observations for horizontal and vertical angles and for azimuth can be determined only by the usual examination and report by the Computing Division of the office." Professor Davies reports that his observations for azimuth at the east end of the base were much broken by the difficulty of seeing the meridian-mark, on account of heavy fog in the valley. On renewing the effort at Quarry Bluff, two hundred and forty-four separate observations were satisfactorily recorded. Five nights were thus occupied with an average of thirty sets of eight pointings each on Polaris and the meridian-mark. Of the work recorded with the theodolite at East Base, Professor Davies says: "This station being a low point in a bend in the Wisconsin River, offered much more difficulty in measuring horizontal angles than had been anticipated from want of clearness in the atmosphere and consequent discordance in the results. During most of the time passed there a cloud of fine sand kept a constant deposit on the theodolite, in spite of the protection afforded by the little wooden building in which the instrument stood." The report notes also that the measurement of vertical angles was made uncertain by unsuitable atmospheric conditions.

Professor Davies kept his party at work in the field until the 20th of October, and thus reports the aggregate statistics of progress:

Signals erected	18
Stations occupied	8
Angles measured	93
Number of observations	6,384

This triangulation includes sixteen townships, within an area of five hundred and seventy-six square miles.

Professor Davies resumed work in the field in June of the present year, and with his party is actively engaged when this report closes. The details now in progress will be mentioned in my next annual report.

SECTION IX.

GULF COAST OF WESTERN LOUISIANA AND OF TEXAS, INCLUDING BAYS AND RIVERS.—(SKETCH No. 17.)

Hydrography of Copano and Saint Charles Bays, Tex.—Lieut. Richard Wainwright, U. S. N., assistant in the Coast Survey, remained during the summer of 1875 in this section with his party in the schooner Bibb. Soundings were completed in Aransas Pass and Corpus Christi Pass, and in the steamboat-channel from Aransas Pass to Corpus Christi Bay. The liability of the passes to change under the action of a gale at any time is a subject of remark in the report of Lieutenant Wainwright. In reference to Corpus Christi Pass he states that the few points found could be recognized with difficulty, being merely the sites of houses that had been moved because of the encroachment

of the water of the Gulf. That pass now opens at a new point and the old channel is closed by a bulkhead.

The shore-lines of Aransas Pass were traced and great alteration showed at the entrance; the point is making from Saint Joseph's Island, and that from Mustang is wearing away.

By continuing work at all favorable intervals the hydrography of Copano Bay and Saint Charles Bay was completed early in September. Currents were observed at and under the surface at times most favorable in reference to the effect of winds, but the results were irregular and such as to yield no conclusion from the short series observed. The statistics of work are as follows:

Miles run in sounding	766
Angles measured	5,848
Number of soundings	78,401

On the morning of the 13th of September, Lieutenant Wainwright crossed the bar of Aransas Pass with the schooner Bibb, and steered for Galveston, with a light wind, which soon fell and was followed by a tremendous gale of four days' duration that submerged parts of the coast of Texas. By the able seamanship of her commander, the little vessel kept the sea and was safely anchored in Galveston Harbor on the 23d of September. Of the incidents of the 16th the report notes: "This evening the barometer reached its lowest point, the wind coming in tremendous puffs, the sea very irregular and boarding us from all points. * * * According to the commonly-received theory of cyclones we were in the forward semicircle and to the left of the path, but the center should have left us to the southward on Wednesday night, though the winds continued to shift more to westward. The lowest barometer, strongest wind, and heavy confused sea were experienced during Thursday night, September 16. At Galveston the wind shifted very suddenly, and that point was probably near the center of the cyclone. It is well known that the rising waters caused nearly all the destruction. Both the outer and inner bars at Galveston were changed by the gale, the channel over the outer bar being farther to the westward than it was before, with fourteen feet of water. The current swept the buoys from the inner bar, and threw them on either side of the channel over the outer bar. When the schooner Bibb left (on the 23d) the current was still running out rapidly, and there was a strong current passing down the coast."

Lieutenant Wainwright was aided in this section by Messrs. E. H. Wyvill and E. B. Pleasants.

The party of Lieutenant Wainwright, with the steamer Arago, was subsequently employed in Section IV.

Reconnaissance of Laguna Madre, coast of Texas.—With a view of extending the survey south of Corpus Christi Bay, Assistant R. E. Halter was assigned to service in this section, and reached Corpus Christi on the 2d of December, 1875. The region below was known to be without inhabitants except such as rove for plunder or resort to it to escape from the laws. Less than twenty miles below the north end of Padre Island Mr. Halter passed the last dwelling-house beyond which the stretch of coast is uninhabited until within a few miles of Brazos. Having sounded through the Laguna to the vicinity of the house just referred to, Assistant Halter there diverged to the westward and examined the shores of Baffin's Bay, which is the only considerable branch of the Laguna Madre. In reference to the entire region he remarks as follows:

"Padre Island is a long, narrow strip varying in width from one to two miles, and is partly covered with sand-hills or dunes ten to fifteen feet high. The general character is like that of the immediate coast that borders the Southern States on the Atlantic. Westward, the Laguna Madre is bounded by uninhabited prairie, the general level of which is about five feet above the water. At places the prairie is undulating, but more commonly is flat and devoid of any vegetation except grass and occasional patches of low, scraggy bushes. These, at a place about eight miles from Flour Bluff, grow to a height of ten feet, and nothing else in the shape of trees was to be found in the region.

"Working southward from Corpus Christi with two men in a small scow, the Laguna was sounded to a point about two miles below Flour Bluff. Thence on in the same direction the channel for five miles has a depth of only eighteen inches, but it then deepens and widens and has plenty of beating-room in four and five feet as far south as the entrance to Baffin's Bay. Below that entrance

the channel, averaging about three feet in depth, narrows again, and many sunken rocks were found on the west side.

"Baffin's Bay has beating-room for six or seven feet of water, but sunken rocks were noticed on both sides of the channel. Rocks are plenty also in the Agua Dolce, which has a depth of three feet; and in the Bovido and Infierno, the two western arms of the bay, in which the average depth is somewhat less.

"In the Laguna Madre rocky bottom is found for about five miles south of Baffin's Bay, but there the rocks disappear, and none were seen in the Laguna north of the bay.

"Ten miles south of Baffin's Bay the depth found in the Laguna was only nine inches. The men refused to pass the scow beyond that shoal barrier. Proceeding in the skiff ten miles farther down the depth found was two and a half feet. This was at a point fifty miles south of the entrance to Corpus Christi Bay. The scow-owners being unwilling to go farther lest their craft might be destroyed by a norther at the barrier, angles were measured from a high sand-hill on Padre Island which afforded a view ten miles farther down the Laguna. The water was continuous, and very probably the moderate depth holds for that distance."

In the course of a second examination made in a flat-boat, Mr. Halter noted the same general features throughout until the shoal was reached, of which mention has been made already. There the depth of nine inches had disappeared and the Laguna was dry. This results usually from a south wind, which doubtless leaves the Laguna occasionally bare at two places between Baffin's Bay and Brazos.

At McGloin's Bluff and Flour Bluff, on opposite shores of Corpus Christi Bay, Assistant Halter found the station-marks which had been placed in the ground by the triangulation-party. Signals were erected at these and at two new points for starting a chain of triangles to include the Laguna Madre. Mr. Halter kept the field until the 1st of June, when the means available for operations having been expended, the party was discharged for the season. He had been previously employed in Section II.

Mr. C. A. Ives and Mr. H. Caperton served as aids in the party of Assistant Halter.

Tidal observations.—The series of observations with a self-registering tide-gauge furnished for the purpose, and forwarded to Saint Thomas, West Indies, was uninterruptedly and very successfully maintained during three entire years, closing in November, 1875, first by Col. W. Thulstrup, and after his return to Europe by Mr. J. Kruse.

The tides at Saint Thomas, as represented by the registers, seem to have been very little affected by winds. The range in rise and fall is only a few inches, but the series will doubtless afford important data for investigating the relations between tides on the coast of our Southern States and those of the West Indies, which at Saint Thomas are probably unmodified ocean-tides. For such comparison provision will be made as already intimated in this report by the establishment of a tidal station at Fernandina, Fla.

SECTION X.

COAST OF CALIFORNIA, INCLUDING THE BAYS, HARBORS, AND RIVERS.—(SKETCHES Nos. 18, 19, 20.)

Reconnaissance from San Pedro eastward toward San Diego, Cal.—For extending the primary triangulation of the coast of California southward to San Diego, a reconnaissance was directed for the selection of stations eastward of San Pedro, at which point the triangulation of the main coast of the Santa Barbara Channel was closed several years ago.

Assistant W. E. Greenwell, having made due preparation at Los Angeles, left that place on the 10th of October, 1875, for the Sierra Madre Mountain. By a trail the party reached a point not far from the summit, and at an elevation of more than four thousand feet above the sea-level. Assistant Greenwell was accompanied by Mr. W. H. Stearns, who aided in the work by visiting in succession the stations at San Pedro and Los Ceritos, in order to determine the certainty of their connection with a point on Santa Anita.

Proceeding subsequently eastward through the mountains, two summits were found to be visible from San Pedro and Anita, furnishing a large quadrilateral, and in the same direction San Bernardino was visited and identified as having been in sight when the party was at Saint Iago and Cucumonga. The summit of the last-named mountain, as determined by the barometer, is 8,450 feet above tide-water. Saint Iago is 5,300 feet high, and was marked by a mound and signal-pole, from the foot of which Mr. Greenwell had in full view Point Loma, the Coronados, Table Mountain, the peak of San José in Lower California; and off our own coast the islands of San Clemente, Santa Catalina, Santa Barbara, and Santa Cruz.

Many summits were reached with great labor and hardship, and subsequently found to be unsuitable in the scheme of triangulation.

Mount San Bernardino was ascended by Assistant Greenwell and Mr. Stearns in the middle of December, and several days were passed in its vicinity. The altitude of the summit is 9,400 feet. This mountain is the initial position of a base-line for the survey of public lands in California, the line terminating westward near Hueneme and to the eastward at the Colorado River.

In the course of the present fiscal year Assistant Greenwell will complete the scheme of main quadrilaterals toward San Diego, and adjust also, if practicable, a subsidiary scheme with stations immediately within reach of the coast.

Survey of Monica Bay, Cal.—For this work the party of Assistant A. W. Chase transferred the camp-equipage from Newport and Anaheim in July, 1875, while Mr. Chase was engaged in completing the office-work of the preceding season. Subassistant Ellicott, who remained with the party until August, selected the site for the working-camp near Santa Monica, and supervised operations in regard to the transfer. After a thorough reconnaissance by Assistant Chase, projections were made for mapping the ground between West Beach Station and Point Dume on three sheets, of which two were to be on the usual scale for topographical work. The intermediate sheet, projected for the immediate vicinity of Santa Monica, was on a larger scale to provide for any emergency that might arise in the local development which was then very active. Of the three sheets, the one here referred to was begun first. Contour-lines were run in the vicinity of the town and mapped to show successive elevations of ten feet. In regard to the tides, the plane of reference adopted coincides with the level of mean low water. The contours over the sloping table-land, back of the town and near the first of the remarkable cañons that put in from the coast-line west and north of Santa Monica, were carefully traced by the use of the level. What are commonly called the "old sea-levels" being well defined along that cañon, special care was taken in determining heights. The western end of the sheet represents the topography as very much broken, and the coast-line is marked by deep cañons that recur at intervals of not more than a quarter of a mile. This detailed survey was carried back to the first of the heavy hills of the Sierra Santa Monica, and shows within the working-limits all elevations under fifteen hundred feet. While the field-work was in progress, many buildings were under construction in the town. These were subsequently added as details of the plane-table survey. Operations were much retarded during the wet season, as the rain-fall was twenty-two inches before the middle of February, 1876. Having traced the shore-line adjacent to Santa Monica, Assistant Chase furnished a duplicate to Lieutenant-Commander Taylor when he arrived at the place with the steamer Hassler; and from time to time the field-party furnished points to guide in the hydrography east and west of the town. By the 10th of December, 1875, Mr. Chase had provided for the uses of the sounding-party, and had furnished shore-line of the entire bight from West Beach to Point Dume. The signals were so erected as to serve for hydrographic purposes as well as for the needful triangulation of that part of the coast.

The middle sheet, showing the vicinity of Santa Monica, was completed and forwarded to the office early in March. Detailed work was then taken up for the sheet eastward of the town, and was prosecuted until the 1st of May. As far as advanced, the sheet represents the shore-line, the large estuary below Santa Monica, and the bluffs in that vicinity. A long range of sand dunes will ultimately appear on the sheet between West Beach and Sand Hill and some isolated hills, which will be useful as pilot-marks. The western sheet as yet represents only the shore-line, but provision has been made for its completion at an early period of the present fiscal year. Mr. T. P. Woodward joined the party of Assistant Chase on the 13th of September, 1875, and served accept-

ably as aid. In the course of the season Mr. Chase furnished, on request, to Lieutenant Wheeler, of the Corps of United States Engineers, data for geographical positions in Los Angeles County, and to Col. J. N. Crawford, chief engineer of the Los Angeles and Independence Railroad Company, a tracing showing contours of ground in the vicinity of Santa Monica. The amount of rainfall the last winter at Santa Monica is the heaviest known in many years. The statistics of field-work are:

Signals erected	14
Stations occupied	6
Angles measured	28
Number of observations	432
Shore-line surveyed, miles	19
Estuary and slough, miles	9
Roads, miles	39
Area of topography, square miles	27½

These statistics do not include about thirteen miles of shore-line traced for the western sheet by means of the theodolite in reconnaissance for the immediate uses of the hydrographic party.

The arrivals of merchant-vessels at Santa Monica during the last six months of the year 1875 included fifty-one steamers and seventeen sailing-vessels, making an aggregate of forty thousand tons.

Hydrography near the Santa Barbara Islands.—At the opening of the present fiscal year Lieut. Commander H. C. Taylor, U. S. N., assistant in the Coast Survey, with his party in the steamer Hassler remained at work in the waters of the Santa Barbara Channel. Four hydrographic sheets then in progress were completed by the end of October, showing soundings along the north and south sides of Santa Rosa Island; also the hydrography of San Miguel Passage, and soundings for developing the vicinity of outlying rocks near that island. A dangerous shoal was developed between San Miguel and Richardson's Rock, having one spot with only twelve feet of water. On the shoal, the depth ranges to three and five fathoms, with twenty to thirty fathoms around the shoal. Lieutenant-Commander Taylor states that oil is emitted in large quantities from deep crevices in the rock bottom of this shoal, and that in the midst of the oil excellent fish of various kinds are readily caught.

After completing hydrography in the vicinity of San Miguel Island, the inshore soundings along the main were extended from Point Concepcion to a point about five miles east of Gaviota.

As mentioned under another head, the party in the steamer Hassler, while in this vicinity, co-operated in the main triangulation by transporting and erecting signals on Santa Barbara Island. The primary signal, as devised and constructed by Engineer Rodes, of the steamer Hassler, consists of cylindrical sections of sheet-iron. Much difficulty was experienced in approaching the island on account of the swell; two of the crew were washed off the face of the cliff, but were recovered; and the detail working under the direction of Lieutenant Talcott, U. S. N., succeeded finally on the 3d of December, in setting up the signal over the primary point of triangulation.

In January last, data were received from Lieutenant-Commander Taylor for fixing the position of a wash-rock in Isthmus Cove, Santa Catalina Island. This rock is part of the dangerous shoal already represented on the chart; but as the rock uncovers only about the time of low-water spring-tides, and then shows about two feet above the water, being covered at other stages of the tide, the chart will be marked accordingly.

In the course of the winter, soundings in the vicinity of Point Dume developed a deep pocket close in with the cape. A large bank was found reaching from the shore through the middle of the Bahia Ona as much as ten miles seaward. On this Lieutenant-Commander Taylor found from twenty-five to forty-five fathoms, but one hundred and two hundred fathoms around the bank.

Dume Cove was developed by sounding and found to be a good anchorage. The holding-ground was tested at intervals in other localities. Late in October the steamer, after taking in coal at San Francisco, commenced soundings in Bahia Ona with special reference to the development of hydrography in the vicinity of Santa Monica. This work was prosecuted at favorable intervals, and was

completed in the middle of March, but as previously stated, the services of the steamer were called for elsewhere temporarily. Sailing-directions for landing at Santa Monica were given on the chart which was turned in by Lieutenant-Commander Taylor. Exposed as the place is to the swell of the sea, the wharf has been built to lessen as much as possible the resulting inconvenience. Of the anchorage it is remarked: "This may be said to extend from one-quarter of a mile offshore in three fathoms to a mile and a quarter offshore in ten fathoms. The holding-ground is excellent, and may be designated as safe, though very uncomfortable."

The aggregate statistics of work done by the party in the steamer Hassler, as represented by six hydrographic sheets, are:

Miles run in sounding	1,271
Angles measured	8,595
Number of soundings	15,634

A survey subsequently made by Lieutenant-Commander Taylor will be noticed presently in its proper geographical order.

During the early part of the present fiscal year Lieuts. George Talcott, George W. Tyler, and J. D. Adams, U. S. N., were attached to the party in the Hassler. Those officers when detached were replaced by Lieutenants Cutts, Wyckoff, and Redfield. Lieuts. Frank Courtis and Richardson Clover, U. S. N., have remained during the year in service with the steamer.

Survey of Catalina Island.—To provide for continuing the survey of the Santa Barbara Channel Islands, Assistant Stehman Forney was authorized to procure a small vessel suitable for the transportation of his party. The vessel was delivered to him at San Francisco on the 21st of October, 1875. A few days after, when completely outfitted, the sloop Catalina was towed to Santa Barbara by the Coast Survey steamer Hassler, and from thence crossed the channel to Catalina Harbor, where the triangulation of the island was commenced. At the outset of the work Mr. Forney selected a site near the harbor and measured a base-line, the ends of which were carefully marked as usual. From the extreme west end of the island the triangulation was extended eastward about nine miles, and in its course includes Catalina Harbor and Isthmus Cove, an indentation on the north side of the island corresponding to the harbor. Work in the field was continued until the 4th of February, when the party was disbanded and the sloop returned to Catalina Harbor. During part of the season Assistant Forney was aided by Mr. W. S. Edwards. The statistics of the work are:

Signals erected	32
Stations occupied	16
Horizontal angle observations	5,685
Vertical angle observations	434

Nine of the peaks and headlands were determined in position and height. To obtain a plane of reference for the heights, Mr. Forney recorded a series of tidal observations at a station on the shore of Catalina Harbor. After leaving the field, duplicates were made of the records, and with the computations, abstracts, and completed plane-table work of the previous season, the results were forwarded to the office. Tracings from the sheets of his detailed survey of Santa Cruz Island were furnished to the Santa Cruz Island Company at the request of the leading officer.

Triangulation across Santa Barbara Channel.—This work has been essentially completed by angular measurements made at two stations on the main east and west of Point Concepcion, in connection with stations on San Miguel Island and Santa Cruz Island. North of Point Concepcion stations have been selected and observed on for continuing the main triangulation toward Monterey Bay, and, as will be seen by the progress-sketch, observations at the station on Anacapa Island will finally complete the triangulation across the Santa Barbara Channel. Assistant O. H. Tittmann left San Francisco with his party on the 8th of September, 1875, and as soon as practicable reached Gaviota Pass. Lieutenant-Commander Taylor being at Santa Barbara with the steamer Hassler, transportation was afforded for crossing to San Miguel and Santa Rosa Islands, where signals were set up. These, because of the difficulty of passing heavy signal-poles across the cañons and over the hills of the islands, were made of sheet-iron in cylinders about eight feet long. One person readily carried a section of the signal and set it up at the station-point. Primary signals were

erected also at Point Sal and at Arguello. Returning to Gaviota, Assistant Tittmann and his aid, Mr. D. B. Wainwright, employed all favorable intervals of weather in the measurement of horizontal angles. Observations were completed at that station on the 6th of December. Incidentally, the lines of level run to the station in May, 1875, were referred to the half-tide level of the ocean by means of a tide-gauge established at Gaviota wharf.

After the completion of work at Gaviota, the camp was removed to the Cañada Honda, at the base of Tranquillon, on which Arguello station is established. Observations were recorded there for latitude and azimuth, in addition to the measurement of horizontal angles. Besides observing on primary lines, the light-house at Point Concepcion was included as a point, and was observed on from Arguello as it had been from the other adjoining primary stations. As the position of the light-house has been determined by astronomical observations, the angular measurements last mentioned afford data for discussion in regard to the very large deflection of the plumb-line in that vicinity. While Mr. Tittmann remained at Gaviota and Arguello, the secondary stations on Santa Rosa and San Miguel Islands, as well as the visible rocks in the vicinity of the latter, were observed on with the theodolite.

Late in February last the party was transferred from Arguello to the east end of Santa Cruz Island. The weather was unfavorable, but the requisite angular measurements were completed by the end of March. The season being too far advanced to warrant the transfer to Anacapa Island under any prospect of continuous weather for observations, the party returned to San Francisco, and was there discharged on the 10th of April.

For latitude, Assistant Tittmann observed during six nights at Gaviota and five nights at Arguello, and recorded two hundred and fifteen observations on forty-four pairs of stars. Azimuth was determined at the two stations by an aggregate of five hundred and forty observations, and the value of the micrometer-divisions was ascertained as usual. At the three primary stations occupied by the party twenty-four hundred and thirty-one measurements of horizontal angles were recorded. Anacapa Island will be occupied by the party of Assistant Tittmann early in the present fiscal year.

Triangulation from Point Sur to Monterey Bay, Cal.—In July, 1875, Assistant A. F. Rodgers and the aid in his party, Mr. E. F. Dickins, made a reconnaissance along the coast from Monterey Bay southward to Point Sur, and set up signals at proper intervals in the following month. Owing to the roughness of the country and difficulties of transportation, most of the work was done under exposure, the party in lieu of tents being sheltered at night in hay-sheds, as the houses of settlers on that part of the coast are generally too small for any inside accommodation to strangers.

Having decided upon the scheme for triangulation the detailed work was left in charge of Mr. Dickins in the absence of Assistant Rodgers, who had proceeded, in accordance with directions, to construct and place an iron signal on the summit of Mount Shasta, further reference to which will be made before closing notices of the work done in this section.

The triangulation along the coast from Point Sur to Monterey Bay was completed in December, Under the direction of Assistant Rodgers, projections for the plane-table survey within the same limits were made by Mr. George Farquhar.

Topography.—In January, field-work was resumed with the plane-table between Monterey Bay and Carmel Bay, and one sheet was filled with topographical details by the end of March; a second sheet was immediately taken in hand and was finished by the end of June.

In addition to the field-work of his party, Assistant Rodgers conducted the details pertaining to the suboffice at San Francisco, which, as the repository of data requisite for the operations of his own and all the other parties, must be managed with systematic care.

The statistics of field-work done between Point Sur and Monterey Bay are:

Signals erected	47
Stations occupied	44
Angles measured	475
Number of observations	10,000
Shore-line surveyed, miles	36
Roads, miles	32
Area of topography, square miles	24

Two additional sheets, which will join at Point Sur, remain for completion hereafter. The coast is very wild in this vicinity, the mountains coming down to the sea for the considerable stretch between Point Sur and Cape San Martin.

Tidal observations.—The observations with self-registering tide-gauge at Fort Point, Cal., and meteorological observations there, have been continued by Mr. E. Gray, under the immediate direction of Col. G. H. Mendell, United States Engineers, who has caused the instructions which were sent from the office to be executed by the observer very satisfactorily. The apparatus continues to work well, and the series in consequence is already very valuable.

Currents of San Francisco Bay.—At the closing of my last annual report Assistant Gershom Bradford was prosecuting the hydrography of the coast of California in the vicinity of Rocky Point. Soon after the opening of the present fiscal year the party returned to San Francisco in the schooner Yukon. After discharging the crew Mr. Bradford took up office-work, and plotted the soundings which he had recorded at Humboldt Bar and Orford Reef, and the additional soundings made on the Cordell Bank. The hydrographic sheets of the coast between Rocky Point and Cape Fortunas were also taken in hand and completed. Special attention was afterward given to the graphic development and tabulation of the currents of San Francisco Bay, in regard to which numerous observations had been recorded. All the original registers, working-sheets, and notes relating to the previous work of the party have been received from Assistant Bradford. Toward the end of the fiscal year his preparations were complete for taking up hydrographic work in Section XI.

Hydrography of Mare Island Strait and Karquines Strait.—An elaborate hydrographic survey of these waters was commenced on the 18th of May, 1876, by the party of Lieut. Commander H. C. Taylor, U. S. N., assistant in the Coast Survey, in charge of the steamer Hassler, and the work was essentially completed by the end of June. In conjunction with soundings, the tides and currents were carefully observed, and to the dangers known as "Gedge Shoal," "Commission Rock," and "Martin's Ledge," special attention was given for their development. The space sounded is comprised between Navy-Yard Slough and Strait Point. Normal to the shores numerous lines of soundings, giving sections of the strait, were run within the limits named, and these were crossed by a few longitudinal lines which were plotted merely as checks upon the working-sheet.

In reference to the results of his survey compared with the existing chart, Lieutenant-Commander Taylor observes:

"A general shoaling of about half a fathom is observable in Mare Island Strait and upon the bar since 1864, and the high and low water lines have encroached somewhat upon the channel, but as a result the current seems to have quickened, and probably the shoaling has nearly or entirely ceased. This surmise, however, has not yet been verified.

"In the river above the navy-yard, the low-water line has encroached slightly upon the channel, but the high-water line has receded considerably, giving a somewhat greater area by high water than before, which seems to indicate that the current in the strait connecting this expanse of water with San Pablo Bay is probably increasing rather than lessening in force."

Where changes in shore-line were noticeable, the present outline was carefully traced in some places by means of the plane-table and in others from numerous points which were determined with the sextant. Lieutenant-Commander Taylor considers as yet undecided the question whether the shoaling at the bar has ceased or is still going on. The statistics of this work are:

Miles run in sounding	127
Angles measured	2, 128
Number of soundings	6, 206

On receipt of the original hydrographic sheet, direction was given for its reduction preparatory to the immediate issue of a chart by the photolithographic process.

Work previously done by the party in the steamer Hassler has been mentioned already in this section of the report.

Primary triangulation.—At the end of February, 1876, Assistant George Davidson, who had conducted a party for observing the last transit of Venus at a station in Japan from which he

returned by the way of India and Europe, presented a comprehensive report on the results of his observations abroad. This includes the subjects of irrigation and land reclamation as practiced in India, Egypt, Italy, the Netherlands, &c.; harbor and river improvements in Asia and Europe; geodetic field-methods in India, and generally the topics on which useful information could be gained by incidental inquiries in the return from a distant foreign country. Proceeding in March to San Francisco, Mr. Davidson resumed charge of the main triangulation for which reconnaissance had been previously made across the Sierra Nevada. In order to ascertain the conditions for field-work with reference to snow on the Sierras, examination was made as far south as the Tehatchepee Pass in April. Mr. Davidson remarks incidentally that the railroad as located through that depression shows engineering skill superior to many instances in India and Europe in overcoming the natural difficulties of the region.

In the Sacramento Valley Professor Davidson selected a site for a base-line, from the ends of which connection is direct with the main triangulation by a well-conditioned quadrilateral. Assistants Cleveland Rockwell and William Eimbeck, who accompanied on this reconnaissance, found the approximate length of the base would be nearly eleven miles. This will be named the "Yolo Base," as it lies in the narrow county of that name.

Signals have been erected at the station-points Monticello and Vaca, and heliotropes were posted at Lola Mountain and Round Top. The last-named station was reached in May by passing through a region thirty miles wide that was then covered with snow. Assistant Davidson has already observed upon the heliotropes at Lola (138 miles distant); and at Round Top, which is 120 miles from the theodolite-station. At the end of June last, when the last report was sent from the field, prospects were good for progress in the triangulation.

Under the immediate direction of Mr. Davidson, Subassistant G. Farquhar has supplied tracings and other data needed from the suboffice in San Francisco by the field and hydrographic parties. Professor Davidson continues, as heretofore, special study for improvements in the astronomical and other instruments requisite for the operations of his party. His suggestions, as embodying the results of large experience and close attention, are noted in the office, and are applied from time to time, as occasion arises, for repairing or modifying the instruments of precision needed in the several processes of the Coast Survey.

So far as now projected, the series of quadrilaterals starting from the vicinity of Mount Diablo where it connects with the primary triangulation of the Pacific, and from which the chain of quadrilaterals is intended to pass eastward, is made up of the longest lines found practicable after a thorough examination of the region. Early in July, Messrs. T. J. Lowry and W. H. Stearns will join the triangulation-party as aids, and it is confidently expected that observations needful for completing the first great quadrilateral of the main triangulation are now advancing toward completion.

Under a call made in the United States Senate, the paper of Professor Davidson embodying his remarks on systems in force for irrigation and land reclamation was sent to that body through the Treasury Department. The paper is of special interest, as already the necessity for plans of irrigation for some of the rich valleys of California has been reported by an able commission as of paramount importance for the region referred to in their report.

Coast topography, north of Bodega Head, Cal.—For continuing the survey of the coast of California northward of Bodega Head, a party organized by Assistant L. A. Sengteller was in the field, near Duncan's Mill, on the 10th of July, 1875. After making a reconnaissance, it was deemed most expedient to begin operations near the upper limit of the contemplated work, and the camp of the party was consequently pitched at Russian Gulch so as to admit of extending the plane-table survey in both directions from that point. By the end of October the work done included the coast-details for a distance about five miles north of Russian Gulch. This embraced a very abrupt and broken coast-line, and represents the ground-surface as rising rapidly in passing from the sea-margin back to the first crest of hills, which show elevations of seventeen hundred feet within a mile and a half of the ocean. Two miles north of Russian Gulch the redwood forest comes to the water-line, and that growth prevails some distance northward toward Point Arena.

From his camp Mr. Sengteller pushed the topographical survey southward as far as the mouth

of Russian River. In general, the character of the coast is similar to that north of the Gulch, but is destitute of timber.

In September, while the plane-table survey was advancing, reconnaissance was made for extending the triangulation northward as far as Stewart's Pass. The scheme decided upon involved much labor and hardship, and was obtained only by climbing every hill or point in the area to be included. The work of triangulation was advanced by occupying Ross Mountain and completing angular measurements on the stations at Bodega Hill and Redwood to the eastward, and to several stations southward and westward of Ross Mountain.

Early in November the party was transferred to a working-camp four miles south of Russian River, and from that point the topographical survey was extended down the coast until the 5th of December. Bad weather throughout the season retarded the field-work on this part of the coast. In the middle of that month the work was resumed above Duncan's Mill, and was continued until the end of February, when the detailed survey of the coast was completed from Salmon Creek northward and westward to a point nearly five miles above Russian Gulch. Mr. G. H. Wilson aided in the field-operations. The statistics are as follows:

Signals erected	4
Stations occupied	9
Angles measured	74
Number of observations	1,423
Shore-line surveyed, miles	17
River and streams, miles	12
Roads, miles	36
Area of topography, square miles	20

After completing his office-work Assistant Sengteller resumed the survey of the coast in the vicinity of Fort Ross, and is now advancing toward Point Arena. Details respecting the work now in progress will be given in my next annual report.

Mount Shasta signal.—Of several plans for a signal that would be visible in clear weather, and sufficient to resist the violence of the elements at a summit 14,400 feet high, one proposed by Assistant C. A. Schott, of the Computing Division, Coast Survey Office, was adopted. The details of construction and the erection of the signal on the summit of Mount Shasta were assigned to Assistant A. F. Rodgers, who had previously tested the practicability of the undertaking by an ascent in April, as mentioned in my last annual report. The signal of galvanized iron is a shaft, in twelve sections, resting upon a base-plate of 8 brass bars bolted together in crib-work form, and surmounted by a copper conoid 3 feet high, nickel-plated and burnished. See accompanying illustration.

The total height of the signal from base to top of conoid is 14 feet 10¼ inches. In order to obtain the greatest possible stability, the shaft when set up was filled to about two-thirds its height with broken rock.

The iron-work for the shaft and the copper conoid being finally complete in accordance with specifications, Assistant Rodgers left San Francisco September 21, and reaching the base of the mountain several days in advance of the material for the signal, at once made preparations for the ascent. Three camps were established at different elevations on the mountain-side, trails were made for the teams requisite, and provisions and forage were stored for the use of the party and horses. The material and outfit arrived at the date expected, and their transfer to the summit was commenced September 29. By the evening of October 5 the whole party had arrived at the summit, the work of excavation for the foundation and sight-lines was completed, and the signal was ready for erection. This work was attended with considerable difficulty, owing to the small space at the summit available for operations, but was successfully accomplished by October 7, and the party then returned to the valley. The progress of the work was favored by two causes, an uncommonly light snow-fall during the preceding season, and the unusually late commencement of the autumnal storms, which generally begin about the end of September, and render the ascent of the mountain impossible until late in June. During their stay at the summit the party suffered from continual

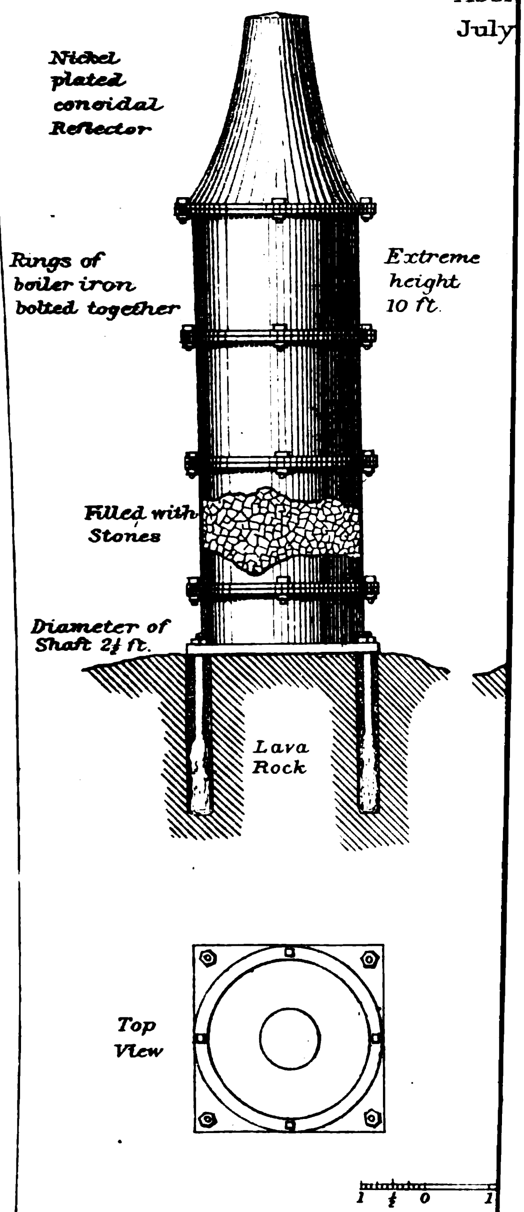
No. 25

Forms for Signal designe

by C.A

Assi

July



headaches, and were unable to sleep, which effects were attributed to the rarefied air at that high elevation.

Observations of horizontal and vertical angles were made by Assistant Eimbeck, who accompanied Mr. Rodgers. A diagram of the signal, sketch showing the general features of the summit, and a collection of specimens of various kinds, were transmitted to the office with the final report after the completion of the work. Under favorable conditions the permanent signal on Mount Shasta will be visible at several of the stations selected by Assistant Eimbeck in his reconnaissance across the Sierra Nevada to the eastward of San Francisco.

SECTION XI.

COAST OF OREGON AND OF WASHINGTON TERRITORY, INCLUDING THE INTERIOR BAYS, PORTS, AND RIVERS.—(SKETCH No. 21.)

Coast topography near Tillamook Bay, Oreg.—When my last annual report closed, Assistant J. J. Gilbert was pushing the plane-table survey of the coast of Oregon southward of Tillamook Head. By the end of September, 1875, the work had been advanced in that direction as far as the entrance to Tillamook Bay, where needful measurements were made for connecting with previous work. Of three sheets resulting from the field-operations in this quarter the middle one represents several miles of the lower part of Nehalem River. Above and below that entrance the numerous heights in view from the coast were observed on, and their approximate positions were marked on the plane-table sheets. The statistics are:

Shore-line surveyed, miles	39
Trails, miles	5
Area of topography, square miles	20

At intervals, while this work was in progress, Assistant Gilbert completed observations for connecting his coast-triangulation with that of the Columbia River. The work done for that purpose is represented in the following synopsis:

Signals erected	6
Stations occupied	16
Angles measured	75
Number of observations	2, 304

Including the signals set up, eighty objects were observed on, the greater number being the heights before mentioned.

Hydrography of the Columbia River.—After the completion of work which has been noticed under the preceding head, Assistant Gilbert transferred his party to Portland, Oreg., and there fitted out for service the Kincheloe, a flat-bottomed boat, and as soon as practicable took up soundings in Columbia River at the limit reached in hydrography by the late Assistant Cordell. Up the river, soundings were advanced as far as Burroughs' Station on the north side and to Puget Station on the Oregon side of the river. Tides were recorded at Cathlamet, W. T., during two lunations, and simultaneous observations were made with a tide-gauge at Clifton, Oreg. Assistant Gilbert commenced hydrographic work in the Columbia on the 15th of October, and soundings were prosecuted until the 15th of December. The statistics are:

Miles run in sounding	214
Angles measured	2, 522
Number of soundings	15, 684

For the adjustment of soundings thirty-four signals were set up along the shores and determined in position by angular measurements with the theodolite.

Winter-rains prevailed during the entire period occupied by the party on the Columbia. The freshet early in the present year was consequently great, and has been the most disastrous ever known. Assistant Gilbert says: "The river, even so near the mouth as Clifton, has risen above all the islands and low lands; the current runs ebb very strong at all times, and the mean rise and fall of tides at Clifton is only about one foot, against six feet last autumn."

Assistant Gilbert was aided in service in this section by Mr. F. Westdahl.

A copy of the plane-table sheet containing the survey of Nehalem River was promptly made by Mr. Gilbert after completing his field-work, and was furnished to General Michler, at the request of that officer. Details on the plane-table sheets of that part of the coast of Oregon represent rocky headlands, sand-beaches, and fringes of the adjacent forest.

On the 1st of June, 1876, after completing the computations of his triangulation of the preceding season, and the plane-table and hydrographic sheets of the work of his party, Mr. Gilbert resumed soundings in the Columbia, and is now extending the hydrography of the river upwards, within the limits of the plane-table survey, the details of which have been mentioned in previous annual reports.

Tidal observations.—Under the direction of Col. G. H. Mendell, United States Engineers, the excellent series of tidal and meteorological observations at Astoria, Oreg., have been kept up by Mr. L. Wilson. The self-registering gauge at this station has been long in use, but registers well under the care and attention of the observer.

Hydrography of Admiralty Inlet, W. T.—At the close of the last fiscal year Assistant J. S. Lawson was completing the survey of the shores and soundings at Duwamish Bay. Subsequently, as the weather of the season allowed, the hydrography of Admiralty Inlet was prosecuted and was extended by the party in the brig Fauntleroy, from Meadow Point northward to Point Elliot in Possession Sound, and westward quite across the inlet from Monroe Point northward to Foulweather Bluff. The soundings include a close examination of the shoal which extends from Wing Point to Blakely Rocks, and development of the approaches to Port Blakely, Eagle Harbor, and Murden's Cove. From Foulweather Bluff and Double Bluff the hydrography to the eastward includes the Scatchet Bank. In that work an amount of anchorage-ground, greater than has been generally known, was developed, especially in what is known as Useless Bay, and on Scatchet Bank. Hitherto the first-named has been looked on with disfavor and even with dread, because as the water shoaled suddenly, it was supposed that vessels had no room to go about after leaving deep water. This applies, however, to the western side of the bay only; on the eastern side the anchorage about a mile from the shore is so good as to make the ordinary name of the bay a misnomer. The bay is not in any sense a harbor from strong winds, but in calms or light winds and head currents the anchorage there would save many miles of lost ground; and Mr. Lawson reports that there is ample sea-room for getting under way without danger in case the wind should spring up from any direction.

"The Scatchet Bank" extends in a direction south-southwest fully three miles and a half toward Apple Tree Cove. Depths on it are very irregular, and at the end of the bank the water suddenly deepens to over one hundred fathoms. When the extent of the bank becomes generally known by the chart, it will be of great benefit to vessels as an anchorage. Until the 1st of September, 1875, Mr. T. P. Woodward was attached to this party as aid. Mr. F. A. Lawson aided in the work throughout the season. The steam-launch Lively, with a separate crew, was in service while soundings were in progress. The following are statistics of the work:

Miles run in sounding	351
Angles measured	1,255
Number of soundings	10,890

Tidal observations.—At Port Townshend, W. T., the series of observations conducted under the direction of Colonel Mendell, United States Engineers, has been continued by Mr. L. Nessel. The pendulum-clock heretofore in use had frequently been stopped by the vibration of the little structure which protects the gauge, but it will be very soon replaced by a balance-wheel clock. An interchangeable cylinder gauge will also be sent to insure the continuity of the series at Port Townshend.

Topography of Puget Sound, W. T.—For this work a party was organized in June, 1876, to work under the charge of Subassistant Eugene Ellicott, whose arrangements at Seattle were in progress when this report was closed. The shores of the sound will be traced south of Restoration Point and Battery Point to Steilacoom, by his party working with a cutter, which has been provided for that and similar service in this section.

Tidal observations.—At the suggestion of W. D. Alexander, esq., superintendent of the Hawaiian Government survey, a tide-gauge has been fitted up and forwarded to Honolulu, where, under the

direction of Mr. Alexander, a series of tidal observations will be recorded. Such a series has been desirable for comparison with the results of tidal observations on the Pacific coast of the United States. The apparatus and registers will be returned to the Coast Survey Office when a satisfactory set of observations is secured.

COAST SURVEY OFFICE.

Assistant J. E. Hilgard has continued in charge of the Coast Survey Office. In the details of executive duty he has been aided by Assistant Edward Goodfellow.

The following abstracts from the reports of the several divisions show the organization of the office and the progress made during the year:

Hydrographic Division.—The duties of hydrographic inspector have been performed by Commander Edward P. Lull, U. S. N.

In administrative details, Commander Lull has had the aid of Lieut. H. E. Nichols, U. S. N., and of Acting Master Robert Platt, the first-named officer having served from July 1 to December 17, 1875, and again from June 15, 1876, till the date of this report; the last-named, from July 1, 1875, to June 7, 1876.

Under the direction of Commander Lull, Mr. E. Willenbucher, hydrographic draughtsman, has plotted, protracted, or drawn eighteen original hydrographic sheets, made nine projections for field-parties, and executed also a large amount of miscellaneous work, consisting in part of tracings, reductions, plotting of positions of buoys, beacons, &c.

Mr. Julius Sprandel, hydrographic draughtsman, has plotted nineteen original hydrographic sheets, made four projections, verified ten original sheets, and made such miscellaneous examinations and reductions as have from time to time been required.

Mr. W. C. Willenbucher, hydrographic draughtsman, has plotted or drawn sixteen original hydrographic sheets, made five projections, and attended to various reductions, tracings, and progress sketches.

Tidal Division.—In this division, under the direction of Mr. R. S. Avery, observations made at eight tidal stations on the Atlantic coast and at four on the Pacific coast were carefully discussed; also, those made at a station in Saint Thomas, West Indies, and at one in Hönolulu, Sandwich Islands.

At the permanent tidal stations, the aim has been to secure periods of observations without interruption, so as to get data for a thorough discussion of all influences affecting the tidal wave. Various expedients have been resorted to at some of the northern stations to prevent the stopping of the gauges by the freezing of the water in the float-tubes.

At North Haven, Me., and at Boston, Mass., heating apparatus has been introduced into the tide-houses. At Governor's Island, N. Y., and Sandy Hook, N. J., a continuous action of the gauge has been obtained by pouring hot water into the float-tubes in severe weather.

Balance-wheel clocks have been substituted for pendulum-clocks as less likely to be stopped by the vibration of the wharves on which the gauges are usually placed. Experiments with wrought-iron enameled tubes are now in progress to test their durability as float-tubes for tidal stations. These are of American manufacture.

The imported staff-gauges, made of sheet-iron covered with porcelain enamel, have proved to be very durable, some of them having withstood for seven years the corroding action of salt-water.

The appended table gives a condensed statement of the tidal observations, not before reported, received at the office from the principal stations. In connection with the several hydrographic surveys, tidal observations are also made which furnish data for charts after being reduced at the office.

The office-reductions of the observations are made at the earliest period practicable, so that the results may serve as a basis for the preparation of tide-tables, and for predicting the times and heights of high and low water at the principal seaports on the Atlantic and Pacific coasts.

These tables for 1877 are now in the hands of the Government Printer, and will be published early in July of the present year.

In the office-work of this division, under the immediate direction of Mr. Avery, have been employed Mr. John Downes, Mr. L. P. Shidy, Mr. F. H. Parsons, and Miss M. Thomas.

Mr. Avery inspected all tidal observations when received, attended to the correspondence with observers and others about tides, arranged and supervised the office-work respecting tides and tide-gauges, made original investigations, and studied improvements.

Mr. Downes was occupied chiefly with the tabulations, reductions, and predictions for tides on the eastern coast.

Mr. Shidy was employed in the reduction, predictions, and discussions for the tidal stations at San Diego, Iliuliuk, North Haven, and Saint Thomas; Mr. Parsons has assisted in miscellaneous computations; Miss Thomas, in addition to her duties in charge of the library, has added hourly readings in suitable groups for discussion, and aided in the general work of the division.

Section.	Name of station.	Name of observer.	Kind of gauge.	Permanent or temporary.	Time of occupation. From—	Time of occupation. To—	Total days.
I	North Haven, Me	J. G. Spaulding	S. R	Permanent	Apr. 29, 1875	Apr. 25, 1876	362
I	Boston navy-yard	H. Howland	S. R	do	June 1, 1875	June 1, 1876	366
I	Providence, R. I	H. H. Brown and R. M. Wood	S. R	do	June 10, 1872	Dec. 31, 1875	1,299
II	Governor's Island, N. Y	R. T. Bassett	S. R	do	May 30, 1875	May 31, 1876	367
II	Brooklyn, N. Y	do	Box	do	May 30, 1875	Dec. 31, 1875	215
II	Sandy Hook, N. J	J. W. Banford	S. R	do	Oct. 21, 1875	June 1, 1876	224
III	Fort Monroe, Va	W. J. Bodell	S. R	do	June 1, 1875	June 1, 1876	366
VIII	New Orleans, La	G. Faust	Staff	Temporary	June 30, 1874	June 30, 1876	731
	Saint Thomas, West Indies	J. Kruse	S. R	do	May 8, 1875	Nov. 9, 1875	186
X	Fort Point, Cal	E. Gray	S. R	Permanent	June 1, 1875	June 1, 1876	366
XI	Astoria, Oreg	L. Wilson	S. R	do	May 1, 1875	May 1, 1876	366
XI	Port Townshend, W. T	L. Nessel	S. R	do	May 1, 1875	May 1, 1876	366
	Honolulu, Sandwich Islands	W. D. Alexander	S. R	Temporary	Aug. 1, 1872	Nov. 12, 1872	104

Computing Division.—Assistant Charles A. Schott has remained in charge of this division. Its general organization has not been changed, but it was found desirable in certain computations to combine the second or office computation with the revision of the field and office work, a duty which was formerly assigned to a third computer. The continued decrease in the number of computers made the new arrangement necessary.

Respecting the *personnel* of this division, Assistant Werner's health continued so feeble that he could perform but a very limited amount of work. Prof. R. Keith resigned in January, 1875, but the astronomical computations were advanced through the employment of Dr. C. Powalky, who, however, was compelled to resign on account of ill health after performing one month's services. We lost, by death, the services of Mr. F. Hudson in April, 1876, leaving at present one astronomical computer for all that class of work. Mr. J. H. Lane, who attended to geodetic computations, was returned to the Weights and Measures Office, after giving two months' work to the Computing Division. The temporary services of Mr. J. Lyons were secured in October, 1875, and retained to the close of the fiscal year. Mr. W. E. Doyle attended to the clerical duties for about a month and a half during the temporary absence of Mr. H. H. Gerdes. Mr. F. C. Donn, Mr. J. B. Baylor, and Subassistant B. A. Colonna were each employed for a short period. It will be noticed in reading the detailed account of work done by each computer, herewith appended, that the present computing force is just about able to keep up the current work, and that very little could be done in bringing up the older work to the standard of the modern work. A great deal of labor will yet have to be performed to adjust, by suitable methods, the secondary and tertiary triangulations to fit to the primary in all those parts of the survey where the latter is essentially completed.

The duties of the chief of the division, in general, consist in distributing, directing, and supervising all computing work; in discussing and reporting results reached; in attending to the correspondence and to special investigations. Among numerous reports submitted by Assistant Schott, the following papers may be specially mentioned: The Polyconic Projection, its relative value compared with other projections, illustrated with 4 plates containing thirty diagrams; Observations of Atmospheric Refraction, contribution No. II, containing comparisons of heights by spirit-level, by the barometer, and the theodolite, and an exposition of the diurnal variation of the refraction; Adjust-

ment of part of primary triangulation in vicinity of Atlanta, Ga.; on Atmospheric Refraction and Adjustment of Hypsometric Measures, contribution No. III. He also made the usual annual determination of the magnetic declination, dip, and intensity at the observatory on Capitol Hill.

The work in detail, done during the fiscal year 1875–'76, by each computer, may be summarized as follows:

Assistant Theodore W. Werner computed the tertiary triangulations of Thames River, Conn., 1874; part of Taunton River, Mass., 1874; part of the junction of the San Joaquin and Sacramento Rivers, Cal., 1867; of the Hudson River near New York, 1875, and of the Great South Bay, Long Island, N. Y., 1874. The computation of the tertiary triangulation of the Dry Tortugas, Fla., 1875, he could not complete for want of health.

Mr. James Main computed and revised the times and astronomical azimuths at stations: Dry Tortugas, Fla., 1875; Santa Barbara, Cal., 1869; Lavender, Ga., 1874; San Buenaventura, Cal., 1869; Middle Base, Atlanta, Ga., 1873; Suwanee, Ga., 1873; Currahee, Ga., 1874; Dominguez, Cal., 1870; New San Miguel, Cal., 1873; Santa Cruz West, Cal., 1874; Maryland Heights, Md., 1870; Clark Mountain, Va., 1871; Bull Run, Va., 1871; Sand Island, N. C., 1876; Last Island, La., 1868; Bluff, Fla., 1876; Rouse's Point, N. Y., 1874; Cheever, N. Y., 1874; Quarry Bluff and East Base, Wis., 1875. He revised the astronomical latitudes of stations: Dominguez, Cal., 1870; San Buenaventura, Cal., 1870; New San Miguel, Cal., 1873; Maryland Heights, Md., 1870; Bull Run, Va., 1871; Clark Mountain, Va., 1871; Sitka, Koh-Klux, Fort Wrangel, Alaska, 1869; Victoria, British Columbia, 1869; Whangaroa, Chatham Islands, South Pacific, 1874; Fort Livingston and Isle Derniere, La., 1853. He also computed the telegraphic difference of longitude between New Orleans and Galveston, Tex., 1868; prepared mean places of stars for field-parties and computed the magnetic observations made at Chatham Islands, 1874.

Dr. Gottlieb Rumpf computed the following triangulations: Of New Orleans, La., 1874; above New Orleans, La., 1875; South Pass, La., 1875; south of entrance of Columbia River, Oreg., 1874; Duwamish Bay, W. T., 1874; Taunton River, Mass., 1874; the junction of San Joaquin and Sacramento Rivers, Cal., 1867; Santa Catalina Island, Cal., 1875–'76. He prepared abstracts of angles at stations Santa Cruz West, Cal., 1874; at stations of the survey of Wisconsin, 1875; computed geodetic latitudes and longitudes of points in Shoalwater Bay, W. T., 1871–'72–'73; adjusted by least squares the old and new triangulations of the Mississippi delta, La., 1857–'58–'59–'60–'66–'75; of Thames River, Conn., 1869 and 1874; and made satisfactory progress with the adjustment of the old triangulation on eastern part of Long Island Sound. He also prepared the annual statistics and data needed by field-parties.

Mr. Edward H. Courtenay computed the least square adjustments of the primary and secondary triangulations of Pamplico Sound, N. C., 1869 to 1875; and of the west end of Albemarle Sound, N. C., 1847–'48; inserted the geodetic results of all triangulations finally revised in the new geographical registers, arranged according to States; revised vertical angles at Ragged, 1874; revised measures of zenith-distances and of micrometric differences of heights of primary and secondary stations, between the Kent Island Base, Md., and Harper's Ferry, Va., 1846 to 1871; and attended to some miscellaneous geodetic computations.

Mr. Myrick H. Doolittle made least square adjustment of observed directions at primary stations: Kenesaw, Ga., 1873; Rabun, Ga., 1875; Spear, Va., 1875; Humpback, Va., 1875; Blood, Ga., 1875; New San Miguel, Cal., 1873; Santa Barbara, Cal., 1862–'63–'69–'70–'74. He also computed the supplementary triangulation of Delaware Bay, 1875; computed heights by spirit-level, coast of Maine, 1874; prepared abstracts of vertical angles at stations Mount Marshall, Va., 1874, and Fork, Va., 1874; computed positions of secondary objects of the triangulation in the vicinity of Atlanta Base, Ga., also between Harper's Ferry and Lynchburg, Va.; and of primary objects between Suwanee and Rabun, Ga., and between Harper's Ferry and Lynchburg, Va., 1870 to 1875. He also solved 25 normal equations of the primary triangulation of Pamplico Sound, N. C.; 21 normal equations of subordinate primary triangulation in same locality; 29 normal equations of the primary triangulation in the vicinity of the Atlanta Base, Ga.; and 18 normal equations for heights, same vicinity, and performed some miscellaneous geodetic computations.

Dr. Charles Powalky after completing the first computation for latitude of station New San Miguel, Cal., 1873, resigned on account of ill health, July 31, 1875.

Mr. J. Homer Lane.—After completing the least square abstract of directions, station Suwanee, Ga., 1873, and commencing the abstract for station New San Miguel, Cal., 1873, Mr. Lane's labors for the Computing Division ceased with August 23, 1875. Between this date and September 30, 1875, when he was assigned to the Weights and Measures Office, he was engaged under the direction of the assistant in charge of the office.

Mr. Frank Hudson computed time and astronomical azimuth at the following stations: Currahee, Ga., 1874; Lavender, Ga., 1874; Middle Base, Atlanta, Ga., 1873; Santa Barbara, Cal., 1869; Santa Buenaventura, Cal., 1869; Dominguez, Cal., 1870; New San Miguel, Cal., 1873; Santa Cruz West, Cal., 1873; Maryland Heights, Md., 1870; Clark, Va., 1871; Bull Run, Va., 1871; and Sand Island, N. C., 1876. Mr. Hudson died suddenly April 10, 1876.

Mr. Joseph Lyons, temporarily attached to the Computing Division, October 22, 1875, was engaged in collating means of angles in original and duplicate records and of reductions in primary triangulations of Northern Georgia and of Santa Barbara Channel, Cal.; attended to the clerical duties of the Computing Division between November 27, 1875, and December 24, 1875; revised abstracts of vertical measures, both of zenith-distances and of micrometric differences, of primary stations in Northern Georgia and along the Blue Ridge in Virginia. He also assisted Mr. Doolittle in the solution of normal equations and prepared the abstract of horizontal directions at primary stations Tobacco Row, Va., 1875, and Long Mountain, Va., 1875. He also attended to miscellaneous computations.

Mr. Herman H. Gerdes attended to the clerical duties of the Computing Division, consisting chiefly in furnishing copies of records and computations to field-parties, and in keeping up the geographical registers of the office; was on leave of absence between November 27, 1875, and February 8, 1876.

Mr. W. E. Doyle discharged the duties of clerk to the Computing Division between December 24, 1875, and February 8, 1876, when he resigned.

Mr. F. C. Donn received instructions in computing between February 18, 1876, and March 14, 1876.

Mr. J. B. Baylor reported for duty as computer May 3, 1876; he was engaged under Mr. Courtenay's direction in making abstracts of angles of certain river-triangulation near Albemarle Sound, N. C., and he was ordered on field-duty June 17, 1876.

Subassistant B. A. Colonna was temporarily assigned to the Computing Division, and between June 16, 1876, and the close of the fiscal year was engaged on the abstract of angles of the triangulation of Pamplico River and of the triangulation of the State of New Hampshire, 1874–'75.

Drawing Division.—This division has continued under the general supervision of Mr. W. T. Bright. Seven persons have been regularly employed throughout the year, briefly as follows: (see also Appendix No. 4).

Mr. A. Lindenkohl has brought up to date the more important finished charts of the coast, upon various scales, consisting of hydrography and topography, and constructed projections upon all the copper plates for new charts commenced by the Engraving Division, and has with a great deal of care and patience adjusted and drawn the usual annual additions to the progress-sketches to accompany the reports to Congress; has made projections for use in the field, and constructed numerous diagrams and miscellaneous maps and charts. Mr. H. Lindenkohl has been employed upon the topography and hydrography of all classes of coast and harbor charts, field-projections, and diagrams, and has given a great portion of his time to the drawing of charts for issue by the photolithographic process, of which this division has, during the past year, completed twelve, or an average of one a month. Mr. L. Karcher has also been employed upon photolithographic charts, tracings, diagrams, and largely upon field-projections, one hundred and three having been constructed and sent from the division.

Mr. P. Erichsen has continued upon diagrams, tracings, projections, and drawing the topographical details upon dry paper impressions containing pantographic outlines, as also upon photographic prints for the $\frac{1}{80000}$ coast-charts. Mr. C. Junken has been engaged mostly upon hydrographic reduction for coast and harbor charts, field-projections, supplying the aids to navigation, and occasionally performing special field-duties. Mr. C. A. Meuth has continued to make titles

for and execute all the general lettering upon the plane-table sheets which are now turned into the office with such lettering in pencil; has traced for photographing for the finished coast-charts on the coast of Maine, three sheets being all that were available during the year. He also made tracings and did other miscellaneous work. Mr. H. Eicholtz has been employed in adding corrections and coloring buoys and light-houses upon the chart-room editions.

The following persons were attached to the division during portions of the year:

Mr. M. Angles was engaged up to the 1st of May, when he quit the office, upon the lettering of photolithographic charts, lettering of plane-table sheets, and miscellaneous duties. Mr. Hull Adams was assigned to duty in the division on the 22d of May, and made copies of field-sketches. Mr. George A. Morrison has performed the clerical duties of the division since December, occasionally doing other work in copying progress-sketches.

Mr. Arthur Schott, who had previously been attached to the division, died July 26, 1875. In addition to the tabular statement of work done by the several draughtsmen as given in Appendix No. 4, and the list of information furnished in reply to special call (Appendix No. 3), the following results of the division are also given:

Projections made for the use of the topographical and hydrographical parties	103
Projects for new charts prepared	28
Projections on copper for engraved charts	10
Photolithographic charts completed	12
Tracings of field-sketches for files of the office	122
Diagrams constructed	38
Topographical sheets drawn for photolithographic reduction	3
Information furnished in form of tracings, &c., in reply to special call	58

Engraving Division.—The charge of this division from the beginning of the fiscal year up to the 29th of March was with Assistant E. Hergesheimer, who for many years had so acceptably performed this duty. Impaired health of some months' duration resulted about that time in serious illness, so that Mr. Hergesheimer was compelled to retire from active service, and was succeeded by Assistant J. S. Bradford, who has since remained in charge. The titles of the engraved plates completed, continued, or begun during the year are given in Appendix No. 5.

Messrs. J. Enthoffer, H. C. Evans, A. Sengteller, W. A. Thompson, A. M. Maedel, and R. F. Bartle have continued work as topographical engravers.

Messrs. E. A. Maedel, F. Courtenay, and A. Petersen have been employed as letter engravers, and Messrs. H. M. Knight, W. H. Knight, J. G. Thompson, John J. Young, E. H. Sipe, and W. H. Davis as miscellaneous engravers. Mr. E. Molkow has continued the use of the pantograph.

The clerical duties of the division have been performed by Mr. L. C. Kerr in a most satisfactory manner, notwithstanding that during the last three months of the year they have been especially onerous.

In the death of Mr. W. H. Knight, which occurred on the 1st of June, the office has sustained a severe loss. He was one of our most valuable engravers.

Electrotyping Division.—Dr. Anton Zumbrock, in charge of this division, reports 36 altos and 39 bassos or printing plates as the number made during the year. In all, 75 plates, weighing 1,626 pounds, and having a surface of 66,324 square inches.

The photographic reductions from original sheets and drawings for the use of the engravers have been made with the aid of a new and improved camera-stand which replaced one destroyed by the storm in February. Five positives, ten negatives, and thirty prints are reported. A new vertical electrotyping-vat, lined with lead, has been set up, the old one being leaky.

All of the silver solutions, varnish, collodion, and other chemical preparations used in the laboratory were made by Dr. Zumbrock. He was aided by Frank Over.

Division of Charts and Instruments.—The labors of this division have been directed as heretofore by Mr. John T. Hoover. He has the immediate supervision of the printing and distribution of charts, of the distribution of the annual reports, and of the dispatch of instruments for field-par-

ties. He has also made the disbursments for office-expenditures under the immediate direction of the assistant in charge of office.

The registering and filing of the original maps, charts, and records of field-work has been continued with Mr. G. A. Stewart.

During the year, 13,235 copies of charts and sketches have been printed. The presses have been worked by Mr. Frank Moore and Mr. D. A. Hoover.

The work of backing with muslin the sheets required for office and field parties, and the miscellaneous duties of the folding-room, were attended to by Mr. H. Nissen.

There has been issued during the year, from the chart-room, under the immediate charge of Mr. T. McDonnell, an aggregate of 12,624 copies of charts. One thousand and forty-eight copies of the annual reports of various years have been distributed.

The work of construction and repair of instruments has been done under the supervision of Mr. John Clark and Mr. G. N. Saegmüller, assisted by J. Foller, W. Jacobi, Werner Suess, and E. Eshleman.

All carpenter-work required in and about the office, including the wood-work of instruments and their packing for transportation, has been done by Mr. A. Yeatman, assisted by F. E. Lackey and James Hess.

Clerical force.—Mr. C. H. Fitch has performed the clerical duties in the office of the assistant-in-charge; Mr. G. A. Morrison those in the Drawing Division during the latter part of the year. In the office of the disbursing agent, Mr. R. L. Hawkins has continued as principal accountant and book-keeper, with Messrs. W. A. Herbert and W. L. Flenner as clerks.

Contingencies that may arise in the operations of a number of parties and vessels widely distributed along the coast, add much to the measure of watchfulness needful in adjusting expenditures for purposes the limits of which can be readily foreseen. In the personal supervision of all items of expenditure incurred in the course of the year, I have been aided by Samuel Hein, esq., the disbursing agent of the survey. Assistant W. W. Cooper has rendered, as heretofore, acceptable service in details under my immediate direction.

Respectfully submitted.

C. P. PATTERSON,
Superintendent United States Coast Survey.

Hon. LOT. M. MORRILL,
Secretary of the Treasury.

APPENDICES.

APPENDIX No. 1.

Distribution of surveying-parties upon the Atlantic, Gulf, and Pacific coasts of the United States during the surveying-seasons of 1875–'76.

Coast-sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION I.				
Atlantic coast of Maine, New Hampshire, Massachusetts, and Rhode Island, including seaports, bays, and rivers.	No. 1	Hydrography	Lieut. Commander C. D. Sigsbee, U. S. N., assistant; Lieuts. J. E. Pillsbury and W. O. Sharrer, U. S. N.; Masters R. G. Peck and M. F. Wright, U. S. N.; Ensign W. E. Sewell, U. S. N.	Lines of deep-sea soundings between the coast of Maine and George's Bank, and development of a rock in the vicinity of Jeffrey's Ledge. (See also Section VIII.)
	2	Triangulation and topography.	J. W. Donn, assistant; F. C. Donn and F. H. Parsons, aids.	Topographical survey of islands near the coast of Maine and between Isle au Haut and Mount Desert. (See also Sections II and III.)
	3	Topography	W. H. Dennis, assistant; H. W. Bache, subassistant; S. N. Ogden, aid.	Detailed plane-table survey of the western shore of Blue Hill Bay, Me. (See also Section V.)
	4	Hydrography	Lieut. J. M. Hawley, U. S. N., assistant; Master G. L. Hanus, U. S. N.; Ensign J. M. Wight.	Soundings along the western side of Deer Isle, coast of Maine, completing the hydrography of Isle au Haut Bay. (See also Section VI.)
	5	Topography	Hull Adams, assistant; W. E. McClintock, aid.	Topographical survey of Northern Bay, near Castine, Me., including the head of Bagaduce River.
	6	Topography	A. W. Longfellow, assistant; W. C. Hodgkins, aid.	Plane-table survey of the east and west shores of Penobscot River, Me., from Bucksport upward to Crosby's Narrows.
	7	Tidal observations	J. G. Spaulding	Series of observations with self-registering tide-gauge continued at North Haven, in Penobscot Bay, Me.
	8	Coast Pilot	J. S. Bradford, assistant; Lieut. C. A. Bradbury, U. S. N.; John R. Barker.	Revision of sailing-directions for the Atlantic Coast Pilot, and views for charts of parts of the coast between Eastport and Penobscot entrance, coast of Maine. (See also Sections II and VI.)
	9	Astronomical observations.	F. W. Perkins, assistant	Special observations at Ragged Mountain, near Camden, Me., for determining the coefficient of refraction. (See also Sections III and VII.)
	10	Triangulation	Prof. E. T. Quimby	Triangulation in New Hampshire continued by angular measurements at Croydon Mountain and Bald Ledge.
	11	Hydrography	F. F. Nes, assistant	Supplementary soundings in the vicinity of Fletcher's Neck and off Old Orchard Beach and Saco River entrance, coast of Maine. (See also Section II.)
	12	Tidal observations	H. Howland	Tidal observations continued at the Charlestown navy-yard (Boston), with self-registering tide gauge.
	13	Triangulation	F. H. Gerdes, assistant; C. H. Sinclair, aid.	Life-saving stations along the coast of New England determined in position by angular measurements, and marked on the original topographical sheets.
	14	Hydrography	F. F. Nes, assistant	Supplementary soundings in the vicinity of Duxbury Pier Light, Plymouth Harbor, and also near Manomet Point, Mass. (See also Section II.)

APPENDIX No. 1—Continued.

Coast-sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION I—Continued.	No. 15	Special	H. Mitchell, assistant	Research in regard to the deposit of material in Plymouth Harbor. (See also Sections II, III, and VIII.)
	16	Hydrography	Lieut. Commander J. C. Kennett, U. S. N., assistant; Acting Ensign George Glass, U. S. N.	Hydrography of the eastern approach to Nantucket Sound, and also near Monomoy Point, Mass. (See also Section VI.)
	17	Hydrography	Lieut. R. D. Hitchcock, U. S. N., assistant; Lieut. James Franklin, U. S. N.; Masters John Hubbard, H. C. T. Nye, and J. L. Hunsicker, U. S. N.	Hydrography including the southern part of the Handkerchief Shoal, Vineyard Sound, Mass. (See also Section VII.)
	18	Topography	A. M. Harrison, assistant; Bion Bradbury and W. B. French, aids.	Topographical survey of the shores of Taunton River, Mass., from Mount Hope Bay upward to Weir Village.
	19	Tidal observations.	J. H. Shedd, civil engineer	Observations continued at Providence, R. I., with self-registering tide-gauge.
	20	Triangulation	J. A. Sullivan, assistant	Light-houses determined in position from Hyannis westward to the vicinity of Greenport, N. Y.
SECTION II.				
Atlantic coast and sea-ports of Connecticut, New York, New Jersey, Pennsylvania, and Delaware, including bays and rivers.	1	Triangulation	R. E. Halter, assistant; H. Caperton, aid.	Triangulation extended to include the vicinity of Connecticut River from previous limits northward to Hartford. (See also Section IX.)
	2	Topography	R. M. Bache, assistant	Detailed topographical survey at the head of New Haven Harbor.
	3	Hydrography	Lieut. C. T. Hutchins, U. S. N., assistant; Masters S. H. May and W. M. Wood, U. S. N.; Ensign H. McCrea, U. S. N.	Hydrographic development of Cumberland Shoal off the east end of Long Island, N. Y., and of the passage between Gull Island and Plum Island. (See also Section V.)
	4	Triangulation	Richard D. Cutts, assistant; J. F. Pratt, aid.	Mount Rafinesque and Greenwich Hill, N. Y., occupied as points in primary triangulation.
	5	Coast Pilot	J. S. Bradford, assistant; Lieut. C. A. Bradbury, U. S. N.; John R. Barker.	Revision of sailing-directions, and views of harbors and landings in Long Island Sound and Hudson River. (See also Sections I and VI.)
	6	Topography	H. L. Whiting, assistant; R. B. Palfrey, aid.	Shore-line survey of New York Harbor from the Narrows northward to Astoria; and from Castle Point to Bull's Ferry.
	7	Special hydrography.	H. Mitchell, assistant; H. L. Marindin, assistant; J. B. Weir, aid.	Physical researches in New York Harbor, including the measurement of sections, and observations on the tides and currents. (See also Sections I and VIII.)
	8	Hydrography	Lieut. H. O. Handy, U. S. N., assistant; Master W. P. Ray, U. S. N.; Ensign F. H. Lefavor, U. S. N.	Current-observations in Hudson River, East River, and New York Harbor; and soundings to develop the vicinity of the Shrewsbury Rocks off the coast of New Jersey.
	9	Tidal observations.	R. T. Bassett	Series of tidal observations continued at Governor's Island, in New York Harbor, with self-registering tide-gauge.
	10	Astronomical observations.	George W. Dean, assistant; J. B. Baylor and Charles Tappan, aids.	Latitude and azimuth determined at Beacon Hill, N. J., and the primary-station point connected with triangulation of New York Harbor.
	11	Hydrography	F. F. Nes, assistant	Fire Island Inlet, N. Y., examined by soundings, and the shore-line changes developed. (See also Section I.)
	12	Triangulation	B. A. Colonna, subassistant	Triangulation of the south coast of Long Island, N. Y., between Babylon and Far Rockaway. (See also Section VIII.)
	13	Topography	C. T. Iardella, assistant; W. Fraser, aid.	Plane-table survey and soundings at the eastern end of Great South Bay, and topography east and west of Babylon, N. Y.
	14	Tidal observations.	R. S. Avery, J. W. Banford	Establishment of a self-registering tide-gauge on the east side of Raritan Bay below Sandy Hook, and commencement of series of observations.

APPENDIX No. 1—Continued.

Coast-sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION II—Continued.	No. 15	Topography	C. M. Bache, assistant; A. G. Pendleton, aid.	Plane-table survey completed in the upper part of Barnegat Bay, N. J., including the vicinity of Tom's River.
	16	Reconnaissance	Prof. E. A. Bowser	Stations selected for determining points in the northern part of New Jersey.
	17	Reconnaissance	Prof. L. M. Haupt	Stations selected for determining points in the Lehigh region of Eastern Pennsylvania.
	18	Hydrography	Lieut. J. M. Grimes, U. S. N., assistant; C. A. Ives, aid.	Hydrography of the Delaware River near Delaware City, and development of a ledge between Marcus Hook and Chester, Pa. (See also Section IV.)
	19	Triangulation	Charles Junken	Range-light located on the New Jersey side of Delaware River above Liston's Tree.
	20	Topography	J. W. Donn, assistant; F. C. Donn and F. H. Parsons, aids.	Topography of sites for range-beacons on the west side of Delaware River near Liston's Tree. (See also Sections I and III.)
	21	Reconnaissance	G. A. Fairfield, assistant	Reconnaissance in the southeast part of Pennsylvania for points of triangulation.
SECTION III.				
Atlantic coast and bays of Maryland and Virginia, including sea-ports and rivers.	1	Special survey	J. W. Donn, assistant	Detailed survey and soundings commenced in Baltimore Harbor for use of the United States commissioners. (See also Sections I and II.)
	2	Special hydrography.	H. Mitchell, assistant; J. B. Weir, E. H. Wyvill, T. A. Harrison, and C. A. Ives, aids.	Physical survey of the channels at Norfolk and Portsmouth, Va., for the adjustment of port-warden lines. (See also Sections I, II, and VIII.)
	3	Tidal observations	W. J. Bodell	Observations continued with self-registering tide-gauge at Fortress Monroe, Old Point Comfort, Va.
	4	Topography	Charles Junken	Topography of part of Smith's Island for State commissioners on the boundary-line between Maryland and Virginia.
	5	Triangulation	F. W. Perkins, assistant; R. E. Duval and J. De Wolf, aids.	Lines of level run from Washington navy-yard to Annapolis, with offsets to "Hill" and "Taylor" primary stations of triangulation. (See also Sections I and VII.)
	6	Magnetic observations.	C. A. Schott, assistant	Magnetic declination, dip, and intensity determined at the standard station on Capitol Hill in Washington City.
	7	Triangulation	J. W. Donn, assistant; F. H. Parsons and F. C. Donn, aids.	Triangulation of the James River, Va., from City Point to Richmond. (See also Sections I and II.)
	8	Triangulation	A. T. Mosman, assistant; W. B. Fairfield, D. S. Wolcott, and C. L. Gardner, aids.	Triangulation continued southward along the Blue Ridge in Virginia. Determination of latitude and azimuth.
	9	Reconnaissance	Edwin Smith, subassistant	Stations selected for continuing triangulation along the Blue Ridge south and west of Lynchburg, Va. (See also Section IV.)
	10	Reconnaissance	S. C. McCorkle, assistant	Reconnaissance in West Virginia for points of triangulation. (See also Section VII.)
SECTION IV.				
Atlantic coast and sounds of North Carolina, including sea-ports and rivers.	1	Hydrography	Lieut. Richard Wainwright, U. S. N., assistant; Master W. P. Ray, U. S. N., Ensign F. H. Lefavor, U. S. N.	Hydrography of Pamplico Sound, N. C., continued along the western side north to Stumpy Point. Survey of Alligator River extended from previous limits south to Blunt's Canal. (See also Section IX.)
	2	Astronomical and magnetic observations.	Edwin Smith, subassistant; J. B. Baylor, aid.	Latitude, azimuth, and the magnetic elements determined at Sand Island, in the northern part of Pamplico Sound, N. C. (See also Section III.)
	3	Hydrography	Lieut. J. M. Grimes, U. S. N., assistant; Master T. G. C. Salter, U. S. N., Ensign O. W. Lowry, U. S. N.	Hydrography of Core Sound, N. C. (See also Section II.)

APPENDIX No. 1—Continued.

Coast-sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION V. Atlantic coast and sea-water channels of South Carolina and Georgia, including sounds, harbors, and rivers.	No. 1	Hydrography.....	Lieut. C. T. Hutchins, U. S. N., assistant; Masters S. H. May and (part of season) W. M. Wood, U. S. N.; Ensign H. McCrea, U. S. N.	Hydrography of Winyah Bay and Georgetown Bar, including the mouths of the Pedee, Waccamaw, and Sampit Rivers. (See also Section II.)
	2	Hydrography.....	Lieut. J. F. Moser, U. S. N., assistant; Master J. B. Murdock, U. S. N.	Hydrography of the water-passages adjacent to Edisto Island, S. C., and soundings near the north end of Hunting Island, S. C.
	3	Triangulation.....	C. O. Boutelle, assistant; H. W. Blair and J. B. Boutelle, aids.	Primary triangulation continued by angular measurements at Mauldin, Paris, and Pinnacle Mountains, S. C., and at Rabun and Blood Mountains in Georgia.
SECTION VI. Atlantic and part of the Gulf coast of the Florida peninsula, including reefs and keys and the sea-ports and rivers.	1	Hydrography.....	Lieut. Commander J. C. Kennett, U. S. N., assistant; Acting Ensign George Glass, U. S. N.	Hydrography of the entrance to Fernandina Harbor, Fla. (See also Section I.)
	2	Triangulation and topography.	H. G. Ogden, assistant; W. I. Vinal, subassistant; F. H. North and J. F. Pratt, aids.	Reconnaissance of the Saint John's River, Fla., from Jacksonville to Lake Monroe; triangulation and shore-line survey from Jacksonville to Mandarin Point.
	3	Triangulation, topography, and hydrography.	Charles Hosmer, assistant; Eugene Ellicott, subassistant; W. E. McClintock and T. A. Harrison, aids.	Detailed survey of the shores and soundings in Indian River, Fla., extended southward to the vicinity of Cape Canaveral.
	4	Hydrography.....	Lieut. C. A. Bradbury, U. S. N., assistant; Master J. H. Coffin, U. S. N.	Hydrography of Key Biscayne Bay, Fla., and sailing-lines for channels across the Florida Reef. (See also Sections I and II.)
	5	Triangulation and topography.	Joseph Hergesheimer, subassistant; Charles Tappan, aid.	Stations selected for the triangulation of Sarasota Bay, Fla. Plane-table survey of the shores of Hillsboro' Bay, Fla.
	6	Hydrography.....	Lieut. J. M. Hawley, U. S. N., assistant; Lieut. U. R. Harris, U. S. N.; Master G. L. Hanus, U. S. N.; Ensign A. H. Cobb, U. S. N.	Hydrography of the Gulf coast near Sarasota Bay and of Hillsboro' Bay, Fla. (See also Section I.)
SECTION VII. Gulf coast and the sounds of West Florida, including ports and rivers.	1	Triangulation, topography, and hydrography.	F. W. Perkins, assistant; J. De Wolf and W. S. Bond, aids.	Detailed survey of the Gulf coast of Florida from Suwanee River northward and westward to Bowlegs Point. (See also Sections I and III.)
	2	Hydrography.....	Master Kossuth Niles, U. S. N., assistant; Masters W. F. Low, H. O. Rittenhouse, and H. W. Schaefer, U. S. N.	Hydrography of Appalachee Bay east and west of the approaches to Saint Mark's Harbor, Fla.; and supplementary soundings in Saint Joseph's Bay (north).
	3	Hydrography.....	Lieut. R. D. Hitchcock, U. S. N., assistant; Lieut. James Franklin, U. S. N.; Masters John Hubbard, H. C. Nye, and J. L. Hunsicker, U. S. N.	Hydrography of the northern coast of the Gulf of Mexico between Saint Andrew's Bay and Mobile Bay. (See also Section I.)
	4	Triangulation.....	F. P. Webber, assistant; F. D. Granger, subassistant; J. H. Christian, aid.	Triangulation in the vicinity of the boundary-line between Northern Georgia and Alabama.
	5	Reconnaissance...	S. C. McCorkle, assistant..........	Reconnaissance for stations in Northern Alabama, to continue triangulation west of the Atlanta base-line. (See also Section III.)
	6	Triangulation.....	Prof. W. Byrd Page...............	Triangulation commenced in Southeastern Kentucky, to extend north and west of Cumberland Gap.

APPENDIX No. 1—Continued.

Coast-sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION VIII.				
Gulf coast and bays of Alabama, and the sounds of Mississippi and Louisiana to Vermilion Bay, including the ports and rivers.	No. 1	Hydrograpahy....	Lieut. Commander C. D. Sigsbee, U. S. N., assistant; Lieuts. J. E. Pillsbury and W. O. Sharrer, U. S. N.; Master R. G. Peck.	Deep-sea soundings in the eastern part and across the Gulf of Mexico, with observations on currents, and for temperature and density. (See also Section I.)
	2	Special survey....	H. Mitchell, assistant; H. L. Marindin, assistant; J. B. Weir, aid.	Special survey of Cubitt's Gap and South West Pass (Mississippi delta), and observations on the tides and currents. (See also Sections I, II, and III.)
	3	Triangulation and topography.	Andrew Braid, subassistant; C. H. Sinclair and C. L. Gardner, aids.	Triangulation and topography of Cubitt's Gap and part of South West Pass, La.
	4	Reconnaissance...	W. H. Dennis, assistant; B. A. Colonna, subassistant; S. N. Ogden and E. B. Pleasants, aids.	Site for base-line and stations selected for the triangulation of Barataria Bay, La. (See also Sections I and II.)
	5	Tidal observations	G. Faust........................	Tidal observations continued with the self-registering gauge at New Orleans, La.
	6	Triangulation, topography, and hydrography.	C. H. Boyd, assistant; Master Alex. McCracken, U. S. N.; C. H. Van Orden and Bion Bradbury, aids.	Survey of the Mississippi River extended from Oakland to Reserve Plantation, and special examination of Bonnet Carre Crevasse.
	7	Triangulation.....	Prof. John E. Davies.............	Triangulation in Wisconsin continued between Prairie du Chien and Madison.
SECTION IX.				
Gulf coast of Western Louisiana and of Texas, including bays and rivers.	1	Hydrography.....	Lieut. Richard Wainwright, U. S. N., assistant; E. H. Wyvill and E. B. Pleasants, aids.	Soundings completed in Copano Bay, Saint Charles Bay, Aransas Pass, and Corpus Christi Pass, Tex. (See also Section IV.)
	2	Reconnaissance...	R. E. Halter, assistant; C. A. Ives and H. Caperton, aids.	Reconnaissance for triangulation of the Laguna Madre, Tex. (See also Section II.)
	3	Tidal observations	Col. W. Thulstrup, J. Kruse......	Series of observations completed with self-registering tide-gauge at Saint Thomas, West India Islands.
SECTION X.				
Coast of California, including the bays, harbors, and rivers.	1	Reconnaissance...	W. E. Greenwell, assistant; W. H. Stearns, aid.	Reconnaissance for primary triangulation between San Diego and San Pedro, Cal.
	2	Topography......	A. W. Chase, assistant; Eugene Ellicott, subassistant; T. P. Woodward, aid.	Detailed plane-table survey of the vicinity of Santa Monica and of the adjacent coast of California.
	3	Hydrography.....	Lieut. Commander H. C. Taylor, U. S. N,, assistant; Lieuts. George Talcott, G. W. Tyler, and J. D. Adams, U. S. N. (part of season); Lieuts. F. Courtis, Richardson Clover, Richard M. Cutts, and A. B. Wyckoff, U. S. N.	Soundings off the coast of California, in the vicinity of Santa Rosa and San Miguel Islands. Inshore hydrography near Point Dume. Survey of Santa Monica Bay, Cal.
	4	Triangulation.....	Stehman Forney, assistant; W. S. Edwards, aid.	Triangulation of the western part of Catalina Island (Santa Barbara Channel), Cal.
	5	Astronomical observations and triangulation.	O. H. Tittmann, assistant; D. B. Wainwright, aid.	Latitude and azimuth determined at a station near Point Conception, Cal. Triangulation across the Santa Barbara Channel to Santa Cruz Island.
	6	Triangulation and topography.	A. F. Rodgers, assistant; E. F. Dickens, aid.	Triangulation and topography of the coast of California between Point Sur and Monterey Bay.
	7	Tidal observations	Col. G. H. Mendell, Corps of United States Engineers; E. Gray.	Series of observations continued at Fort Point, Cal., with self-registering tide-gauge. (See also Section XI.)
	8	Hydrography.....	Gershom Bradford, assistant......	Observations on the currents of San Francisco Bay, Cal.
	9	Hydrography.....	Lieut. Commander H. C. Taylor, U. S. N., assistant; Lieuts. Frank Courtis, Richardson Clover, Richard M. Cutts, and A. B. Wyckoff, U. S. N.	Hydrographic survey of Mare Island Strait and Karquines Strait, Cal.

APPENDIX No. 1—Continued.

Coast-sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION X—Continued.	No. 10	Primary triangulation.	George Davidson, assistant; C. Rockwell and W. Eimbeck, assistants; T. J. Lowry and W. H. Stearns, aids.	Selection of the Yolo base-line and triangulation in its vicinity, for crossing the Sierra Nevada from Mount Diablo, Cal.
	11	Triangulation and topography.	L. A. Sengteller, assistant; George H. Wilson, aid.	Detailed survey of the coast of California from Bodega Head northward towards Fort Ross.
	12	Station-mark......	A. F. Rodgers, assistant; W. Eimbeck, assistant.	Establishment of a permanent signal, of iron, on the summit of Mount Shasta, Cal.
SECTION XI.				
Coast of Oregon and of Washington Territory, including the interior bays and the ports and rivers.	1	Triangulation, topography, and hydrography.	J. J. Gilbert, assistant; F. Westdahl.	Triangulation and topography of the coast of Oregon above and below Nehalem River. Hydrography of the Columbia River within previous topographical limits.
	2	Tidal observations	Col. G. H. Mendell, United States Engineers; L. Wilson.	Observations continued at Astoria, Oreg., with self-registering tide-gauge. (See also Section X.)
	3	Hydrography	James S. Lawson, assistant; T. P. Woodward and F. A. Lawson, aids.	Soundings completed in Admiralty Inlet, W. T., from Duwamish Bay northward to Port Madison.
	4	Tidal observations	Col. G. H. Mendell, United States Engineers; L. Nessel.	Tidal observations at Port Townshend, W. T., continued with self-registering gauge. (See also Section X.)
		Tides of the Pacific Ocean.	W. D. Alexander, esq., superintendent of the Hawaiian Government survey.	Series of observations commenced with a self-registering tide-gauge at Honolulu, Sandwich Islands.

APPENDIX No. 2.

Statistics of field and office work of the United States Coast Survey to the close of the year 1875.

Description.	Total to December 31, 1874.	1875.	Total to December 31, 1875.
RECONNAISSANCE.			
Area in square statute miles	100,550	66,840	167,390
Parties, number of, in year	....	4	....
BASE-LINES.			
Primary, number of	13	....	13
Subsidiary, number of	97	5	102
Primary, length of, in statute miles	79	....	79
Subsidiary and line measures, length of, in statute miles	225½	6¼	231¾
TRIANGULATION.			
Area in square statute miles	71,580	13,600	85,180
Stations occupied for horizontal angles, number of	8,040	274	8,314
Geographical positions determined, number of	14,991	376	15,367
Stations occupied for vertical angles, number of	432	81	463
Elevations determined, number of	963	73	1,036
Lines of spirit-leveling, length of	583½	46½	630
Parties (triangulation and leveling), number of in year	....	27	....
ASTRONOMICAL WORK.			
Azimuth-stations, number of	119	7	126
Latitude-stations, number of	213	4	217
Longitude-stations (telegraphic), number of	83	....	83
Longitude-stations (chronometric and lunar), number of	110	....	110
Astronomical parties, number of	....	7	....
MAGNETIC WORK.*			
Stations occupied, number of	370	14	384
Permanent magnetic stations, number of	....	1	....
Magnetic parties, number of, in year	....	4	....
TOPOGRAPHY.			
Area surveyed in square miles	24,732	476	25,208
Length of general coast in miles	5,646	102	5,748
Length of shore-line in miles (including rivers, creeks, and ponds)	68,910	1,465	70,375
Length of roads in miles	36,101	664	36,765
Topographical parties, number of, in year	....	25	....
HYDROGRAPHY.			
Parties, number of, in year	....	28	....
Number of miles run while sounding	277,909	14,158	292,067
Area sounded, in square miles	68,205	2,442	70,647
Miles run additional of outside or deep-sea soundings	44,371	5,073	49,444
Number of soundings	12,793,247	739,819	13,533,066
Soundings in Gulf Stream for temperature	4,072	....	4,072
Tidal stations, permanent	193	10	203
Tidal stations occupied temporarily	1,494	72	1,566
Tidal parties, number of, in year	....	40	....
Current-stations occupied	157	89	246
Current-parties, number of, in year	....	2	....
Number of deep-sea soundings	....	1,301	....
Specimens of bottom, number of	10,394	29	10,423
RECORDS.			
Triangulation, originals, number of volumes	1,840	175	2,015
Astronomical observations, originals, number of volumes	1,114	76	1,190
Magnetic observations, originals, number of volumes	323	30	353

* Under the heads of "Reconnaissance," "Base-lines," "Triangulation," "Astronomical Work," and "Magnetic Work," items have been included not heretofore counted, or counted upon a different principle; hence some apparent discrepancies in summation with figures given in previous reports.

APPENDIX No. 2—Continued.

Description.	Total to December 31, 1874.	1875.	Total to December 31, 1875.
RECORDS—Continued.			
Duplicates of the above, number of volumes	2, 106	103	2, 209
Computations, number of volumes	2, 145	174	2, 319
Hydrographical soundings and angles, originals, number of volumes	6, 435	437	6, 872
Hydrographical soundings and angles, duplicates, number of volumes	608	106	714
Tidal and current observations, originals, number of volumes	2, 543	291	2, 834
Tidal and current observations, duplicates, number of volumes	1, 846	44	1, 890
Sheets from self-registering tide-gauges, number of	2, 250	102	2, 352
Tidal reductions, number of volumes	1, 565	39	1, 604
Total number of volumes of records	20, 525	1, 475	22, 000
MAPS AND CHARTS.			
Topographical maps, originals	1, 419	51	1, 470
Hydrographic charts, originals	1, 324	39	1, 363
Reductions from original sheets	765	14	779
Total number of manuscript maps and charts to and including 1875	2, 526	14	2, 540
Number of sketches made in field and office	2, 835	68	2, 903
ENGRAVING AND PRINTING.			
Engraved plates of finished charts, number of	195	9	204
Engraved plates of preliminary charts, sketches, and diagrams for the Coast Survey Reports, number of.	560	2	562
Electrotype-plates made	1, 090	56	1, 146
Finished charts published	177	14	191
Preliminary charts and hydrographical sketches published	464	20	484
Printed sheets of maps and charts distributed	326, 276	19, 374	345, 650
Printed sheets of maps and charts deposited with sale-agents	119, 152	7, 750	126, 902
LIBRARY.			
Number of volumes	5, 657	334	5, 991
INSTRUMENTS.			
Cost of	$102, 394. 82	$6, 953. 00	$109, 347. 82

APPENDIX No. 3.

Information furnished from the Coast Survey Office, by tracing from original sheets, &c., in reply to special calls during the year ending July 1, 1876.

Date.		Name.	Data furnished.
1875.			
July	2	Maj. George H. Thom, United States Corps of Engineers	Hydrographical and topographical surveys of Ipswich Harbor and River, Mass.
	2	......do	Hydrographical survey, adjacent to Matinicus and Ragged Islands, showing Matinicus Roads, Me.
	7	S. T. Abert, United States civil engineer	Topographical survey of the coast of North Carolina from Beaufort to New River Inlet.
	10	......do	Topographical survey of the coast of North Carolina from New River to Stump Inlet.
	10	......do	Topographical survey of the coast of North Carolina from Stump Inlet to Old Topsail Inlet.
	10	......do	Topographical survey of the coast of North Carolina from Old Topsail Inlet to head of sound.
	14	Maj. N. Michler, United States Corps of Engineers, light-house engineer thirteenth district.	Topographical and hydrographical survey of entrance to Nehalem River, Oreg.
	17	J. B. Eads, chief engineer South Pass jettee works	Tracing showing soundings and cross-sections of South Pass and Bayou Grande, Mississippi River.
	19	S. T. Abert, United States civil engineer	Hydrographical survey of the Nansemond River to town of Suffolk, Va.
	19	J. Bradford, esq., assistant surveyor-general of Louisiana.	Data of triangulation at South Pass for determining township-lines.
	23	United States Light-House Board	Hydrographic survey of the Delaware River from Ship John Shoal to Fort Delaware.
	29	A. T. Snell, esq., inspector twelfth light-house district.	Topographical survey of Santa Ana Lagoon, Cal.
August	12	J. W. Thompson, esq., president of the Inland and Seaboard Coasting Company.	Table of distances on the Potomac River and Chesapeake Bay.
	11	British Admiralty	Depths on rocks in San Luis Obispo Bay, Cal.
	20	War Department	Hydrographical survey of the South Pass from Head of Passes to East Point, scale 1-4,800, and diagram maps of Cubit's Crevasse and The Jump.
	24	......do	Cross-sections of South Pass and Bayou Grande for computations of volumes passing per hour.
	24	......do	Copy of soundings outside of South Pass Bar, scale 1-20,000.
	24	......do	Hydrographic surveys of Head of Passes and South Pass Bay, on a scale of 1-2,400,
	24	Warburton S. Warren, esq., Manatee, Fla	Topographical survey of Manatee River and Terraceia Bay, Tampa Bay, Fla.
September	11	United States Light-House Board	Topographical survey of Point Sur, Cal.
	6	United States Advisory Council for Norfolk Harbor	Compiled chart of the Elizabeth River, Va., from Tyrant Creek to Pinner's Point, one-third of a mile above United States navy-yard, and to the third bridge in the Eastern Branch, containing shore-line points of triangulation and depth-lines; scale 1-5,000.
	6	......do	Compiled chart of Elizabeth River, Va., from Norfolk to Hampton Roads, containing shore-line, curves of depths, soundings, triangulation, and topographical stations; scale 1-10,000.
	6	......do	Compiled chart of Elizabeth River, Va., from Pinner's Point to Dismal Swamp Canal, including Eastern Branch to third bridge, containing shore-line, curves of depth, soundings, triangulation, and topographical stations; scale 1-10,000.
November	15	United States Light-House Board	Chart of the Delaware River, with Liston's signal-ranges on.
	17	Col. Andrew Talcott	Unfinished proof of Coast chart No. 91, with curves and scales added.
December	2	Abel Hawley, esq	Hydrographic survey of Aransas Pass, Tex., from the survey of 1875.
	17	United States Light-House Board	Chart of entrance to Schuylkill River, showing range-lights as determined in December, 1875.
	17	United States Advisory Council for Norfolk Harbor	Comparative chart of the Elizabeth River from Craney Island light-house to United States navy-yard, Norfolk, from the surveys made in 1854 and 1872–'73.
	30	Mr. C. H. Bliss, Washington City	Hydrographic and topographical survey of the Potomac River, vicinity of the Three Sisters.

APPENDIX No. 3—Continued.

Date.		Name.	Data furnished.
1876.			
January	6	Col. O. M. Poe, United States Corps of Engineers	Positions of Army stations above city of Savannah, Ga.
	17	I. C. Brainard, M. D., New York	Hydrographic information of Saint George's Sound, Fla., from the surveys of 1871–'72 and 1875.
	19	J. B. Thompson, M. D., Portland, Me	Unfinished proof of Coast chart No. 4, Naskeag Point to Whitehead light, including Penobscot Bay, Me.; scale 1-80,000, with islands lettered about Isle au Haut, Me.
	22	Hon. G. N. Fox	Information concerning the Isle of Shoals, New Hampshire and Maine, and distances and bearings of places near the town of Fryeburg, Me.
	24	Hon. Gustave Schleicher, of Texas	Hydrographical information of the coast of Texas from Galveston to Corpus Christi, and part of the Laguna Madre from Corpus Christi to Baffin's Bay.
	29	The American Cyclopædia, New York	Length of the Atlantic, Gulf, and Pacific coasts of the United States; also length of shore-line of the American portion of the Great Lakes, together with length of British and Mexican boundary-lines.
February	1	Rev. J. Wentworth Leigh	Topographical survey of Butler's Island, on Altamaha Sound, Ga.
	14	Charles H. Haswell, esq., New York	Topography of Barren Island, in Jamaica Bay, Long Island.
	16	Gen. A. A. Humphreys, Chief of United States Corps of Engineers.	Hydrographic charts of Saint Mary's River bar and entrance, from the surveys made in 1874 and 1876.
	18	Gen. E. O. C. Ord, United States Army	Three proofs of Coast chart No. 107, Matagorda Bay, Tex., dates and limits of topography and hydrography.
	29	Thomas S. Hardee, city surveyor of New Orleans	Topographical survey of the city of New Orleans, from the survey of 1874–'75.
March	8	Senator James L. Alcorn	Shore-line data of the sea-coast States and Territories.
	10	Hon. G. N. Fox	Tracing of Carroll County, in New Hampshire, and adjoining counties in Maine, from Walling's map of 1862.
	14	Lieut. George M. Wheeler, United States Corps of Engineers.	Tracing from drawing of Santa Barbara Channel from Point Vincent to Point Concepcion, Cal.
April	4	W. J. Lewis, Clinton, Conn	Topographical and hydrographic survey of Duck Island Harbor between Clinton and Westbrook, Conn.
	17	A. C. Rhind, light-house inspector, third district New York.	Hydrography of Fin Island Inlet, Long Island, N. Y.
	19	Hon. Gustave Schleicher, of Texas	Copy of the hydrographic resurvey of Aransas Pass of August, 1875.
	24	William L. Putnam, attorney at law, Portland, Me	Hydrographical survey of Portland Harbor of 1853.
May	2	J. W. Hawes, of the American Cyclopædia	Distances from Washington by way of Potomac River and to mouth of Chesapeake Bay.
	13	S. T. Abert, United States civil engineer	Hydrography of Elizabeth River and southern branch from Hospital Point light-house to United States navy-yard, including Norfolk Harbor to first bridge.
	13	......do	Hydrographic survey of Mackay's Creek and approaches, James River, Va., from the survey of 1849.
	17	......do	Hydrographic survey of Elizabeth River from Craney Island to Norfolk, Va.
	27	James F. Rusling, pension agent, Trenton, N. J	Approximate extent of the sea-coast of the United States and Alaska.
June	6	Gen. J. G. Barnard, United States Corps of Engineers	Hydrographic survey, Head of Passes, Mississippi River, 1875; scale 1-2,400.
	22	......do	Hydrographic survey of South Pass from Head of Passes to East Point; scale 1-4,800.
	28	Lieut. George M. Wheeler, United States Corps of Engineers.	Geographical positions, description of stations, and topographical survey of San Buenaventura, Cal.

APPENDIX No. 4.

DRAWING DIVISION.

Charts completed or in progress during the year ending July 1, 1876.

1. Hydrography. 2. Topography. 3. Drawing for photographic reduction. 4. Details upon photographic outlines. 5. Verification. 6. Lettering.

Title of chart.	Scale.	Draughtsmen.	Remarks.
Coast chart No. 3, Petit Menan light to Naskeag Point	1-80, 000	2. C. A. Meuth. 2. P. Erichsen	Continued.
Coast chart No. 4, Naskeag Point to Whitehead light, including Penobscot Bay, Me.	1-80, 000	1 and 2. A. Lindenkohl. 2. P. Erichsen	Do.
Sailing charts Nos. 1 and 2, Cape Sable to Cape Hatteras	1-1, 200, 000	1. A. Lindenkohl	
Belfast Bay and Penobscot River, Me	1-40, 000	1. A. Lindenkohl	Do.
Belfast Bay, Me	1-20, 000	1. C. Junken	Additions.
Bar Harbor	1-10, 000	1. C. Junken	Completed.
Blue Hill and Union River Bays, Me	1-40, 000	2. P. Erichsen	Commenced.
Frenchman's Bay and Some's Sound, Mount Desert Island, Me.	1-40, 000	2. P. Erichsen	Do.
Portland Harbor, Me	1-1, 200	2. H. Lindenkohl. 2. L. Karcher	Special maps of the city.
Portsmouth Harbor, N. H	1-20, 000	1 and 2. C. Junken	New edition; completed.
General coast chart No. II, Cape Ann to Gay Head, Mass.	1-400, 000	1. A. Lindenkohl	Additions; continued.
Salem Harbor, Mass	1-25, 000	1. C. Junken	Additions; completed.
Plymouth Harbor, Mass	1-40, 000	1. H. Lindenkohl	Do.
Isles of Shoals, Me. and N. H	1-20, 000	L. Karcher	New edition; completed.
Burlington Harbor, Vt	1-10, 000	1. C. Junken	Additions; completed.
Lake Champlain, No. 3, from Ligonier Point to Panton	1-40, 000	1. A. Lindenkohl. 1 and 2. H. Lindenkohl. 1. C. Junken.	Completed.
Do	1-50, 000	1 and 2. H. Lindenkohl	Photolithograph; completed.
Lake Champlain, No. 4 (in two parts), from Panton to Whitehall.	1-40, 000	1 and 2. A. Lindenkohl. 1 and 2. H. Lindenkohl. 1. C. Junken.	Completed.
Lake Champlain, No. 4 (part first), Panton to Fort Ticonderoga.	1-50, 000	1 and 2. H. Lindenkohl	Photolithograph; completed.
Lake Champlain, No. 4 (part second), Fort Ticonderoga to Whitehall.	1-25, 000	1 and 2. A. Lindenkohl and H. Lindenkohl	Do.
Coast chart No. 13, Cuttyhunk to Block Island, including Narragansett Bay.	1-80, 000	1. H. Lindenkohl	Additions.
Monomoy entrance to Nantucket Sound	1-30, 000	1. L. Karcher	Completed.
Coast chart No. 15, middle sheet, from Point Judith and Block Island to Plum Island.	1-80, 000	1. H. Lindenkohl	Additions; completed.
New Haven Harbor, Conn	1-20, 000	1. C. Junken	Do.
Sailing charts Nos. II and III, from Nantucket to Mosquito Inlet, Fla.	1-1, 200, 000	1. A. Lindenkohl	Additions.
Coast chart No. 20, New York Bay and Harbor	1-80, 000	1. C. Junken. 1. L. Karcher	Do.
Coast chart No. 22, Barnegat Bay to Absecum light	1-80, 000	2. A. Lindenkohl. 2. H. Lindenkohl	Continued.
New York Harbor (lower)	1-40 000	2. A. Lindenkohl. 1 and 2. C. Junken. 1. L. Karcher.	Do.
Hackensack River, N. J	1-20, 000	1 and 2. P. Erichsen	Commenced.
Fire Island Inlet, N. Y	1-25, 000	1 and 2. A. Lindenkohl. 2. H. Lindenkohl. 1. C. Junken.	Completed.
Coast chart No. 25, middle sheet, part of Delaware Bay and River.	1-80, 000	1. A. Lindenkohl	Additions.
Coast chart No. 26, upper sheet, Delaware River, Wilmington to Trenton.	1-80, 000	1. A. Lindenkohl	Do.
Schooner Ledge, Delaware River	1-20, 000	1 and 2. A. Lindenkohl. 1 and 2. H. Lindenkohl.	Photolithograph; completed.
General coast chart No. V, Cape Henry to Cape Lookout.	1-400, 000	1. A. Lindenkohl. 2. A. Lindenkohl	Additions.
Coast chart No. 40, Albemarle Sound, eastern sheet, including Currituck, Croatan, and Roanoke Sounds.	1-80, 000	1. C. Junken	Do.
Coast chart No. 43, middle sheet, Ocracoke Inlet to mouth of Pamplico River.	1-80, 000	2. P. Erichsen	Do.

APPENDIX No. 4—Continued.

Title of chart.	Scale.	Draughtsmen.	Remarks.
Coast chart No. 51, part of Long Bay, including Little River Inlet.	1–80, 000	2. A. Lindenkohl	Commenced.
Core Sound, N. C	1–40, 000	2. H. Lindenkohl. 1. C. Junken. 1. L. Karcher.	Additions; completed.
General coast chart No. VII, Cape Romain to Saint Mary's River, Fla.	1–400, 000	2. A. Lindenkohl	Additions.
Coast chart No. 55, from Hunting Island to Ossabaw Sound, Ga.	1–80, 000	2. A. Lindenkohl	Additions; completed.
Inside passage, between Coosaw and Broad Rivers, S. C	1–80, 000	2. P. Erichsen	Completed.
Saint Helena Sound, S. C	1–40, 000	1. C. Junken	Additions; completed.
Savannah River, Ga	1–40, 000	1. C. Junken	New edition; continued.
Coast chart No. 70, Key West, Marquesas Keys	1–80, 000	1. C. Junken	Completed.
Coast chart No. 71, Tortugas, Loggerhead, and Garden Keys.	1–80, 000	1 and 2. A. Lindenkohl	Do.
Coast chart No. 83, Apalachicola Bay, Cape San Blas, and part of Saint Joseph's Bay.	1–80, 000	1 and 2. A. Lindenkohl. 1. H. Lindenkohl.	Additions; continued.
Coast chart No. 88, Mobile Bay, Ala	1–80, 000	1. C. Junken	Additions.
Tampa Bay entrance, Fla	1–40, 000	1 and 2. A. Lindenkohl. 2. H. Lindenkohl. 1. C. Junken.	Completed.
Inside passages, from head of Halifax River toward Cape Canaveral.	1–15, 000	L. Karcher	Commenced.
Entrance to Pensacola Bay	1–30, 000	1. A. Lindenkohl	Additions.
General coast chart No. XIII, from Cape San Blas to Southwest Pass.	1–400, 000	1 and 2. A. Lindenkohl. 2. L. Karcher	Additions; continued.
Coast chart No. 95, Mississippi River from the forts to New Orleans.	1–80, 000	2. H. Lindenkohl	Commenced.
Head of Passes, Mississippi Delta	1–2, 400	1. C. Junken (plotting hydrography)	Completed.
Coast chart No. 106, from Oyster Bay to Matagorda Bay	1–80, 000	1. A. Lindenkohl	Additions; continued.
Coast chart No. 107, Matagorda Bay	1–80, 000	1. C. Junken	Do.
Coast chart No. 108, Pass Cavallo and San Antonio Bay	1–80, 000	1. A. Lindenkohl	Do.
Aransas Pass, Tex	1–1, 500	1. H. Lindenkohl. L. Karcher	Photolithograph; completed.
Sailing chart No. 5, Key West to Rio Grande	1–1, 200 000	1. A. Lindenkohl. 1. L. Karcher. 1. C. Junken.	Additions.
San Luis Obispo Bay, Cal	1–20, 000	H. Lindenkohl	Photolithograph; completed.
San Francisco Bay and entrance, Cal	1–50, 000	1. L. Karcher	Additions; completed.
Do	1–40, 000	1. A. Lindenkohl	New edition.
Santa Monica, Cal	1–20, 000	1. C. Junken. 1. M. Angles. 1. H. Lindenkohl.	Photolithograph; completed.
Aleutian Islands	1–2, 400, 000	1 and 2. A. Lindenkohl. 1 and 2. H. Lindenkohl.	Completed.
Whangaroa Harbor, Chatham Islands		H. Lindenkohl. C. A. Meuth	Photolithograph; completed.
Columbia River, Oreg. (sheet No. 2)	1–40, 000	2. H. Lindenkohl	Additions.
Budd's Inlet, W. T	1–20, 000	1. C. Junken. 1 and 2. H. Lindenkohl	Photolithograph; commenced.
Harbors of Alaska		1 and 2. H. Lindenkohl	Completed.
Centennial map of Atlantic, Gulf, and Pacific coasts	1–1, 200, 000	A. Lindenkohl. H. Lindenkohl. C. Junken, C. A. Meuth.	Do.
Triangulation sketch, Maine to New York	1–400, 000	A. Lindenkohl. H. Lindenkohl	Do.
Siphon of the Cavour Canal		H. Lindenkohl	Photolithograph; completed.
Dam across the river Soane		H. Lindenkohl	Do.
Irrigation maps		P. Erichsen. George A. Morrison	Do.
Magnetic map of the United States		A. Lindenkohl	Completed.
General progress sketch for 1874–'75	1–5, 000, 000	A. Lindenkohl	Do.

APPENDIX No. 5.

ENGRAVING DIVISION.

Plates completed, continued, or commenced July 1, 1875, to June 30, 1876, inclusive.

1. Outline. 2. Topography. 3. Sanding. 4. Lettering.

Title of plates.	Scale.	Engravers.
COMPLETED.		
General coast-charts.		
No. VII, from Cape Romain, S. C., to Amelia Island, Fla	1-400, 000	1 and 2. W. A. Thompson. 3. H. M. Knight. 4. H. M. Knight and W. H. Davis.
Approaches to New Orleans, La	1-400, 000	1 and 2. W. A. Thompson. 3. H. M. Knight. 4. J. G. Thompson and W. H. Davis.
Coast-charts.		
No. 40, Albemarle Sound, N. C. (eastern sheet)	1-80, 000	2 and 3. H. M. Knight. 4. A. Petersen and J. G. Thompson.
No. 54, from Long Island, S. C., to Hunting Island, S. C	1-80, 000	4. H. M. Knight.
No. 55, from Hunting Island, S. C., to Ossabaw Sound, Ga	1-80, 000	4. E. A. Maedel.
No. 56, from Savannah, Ga., to Sapelo Island, Ga	1-80, 000	2. A. Sengteller. 4. J. G. Thompson and H. M. Knight.
No. 57, from Sapelo Island, Ga., to Amelia Island, Fla	1-80, 000	2. A. Sengteller. 3. H. M. Knight. 4. E. A. Maedel and J. G. Thompson.
Harbor-charts.		
Eastport Harbor, Me. (preliminary edition)	1-40, 000	1, 2, and 4. J. G. Thompson. 3. H. M. Knight.
Mount Desert Island, Me	1-80, 000	2. J. Enthoffer. 4. E. A. Maedel and J. G. Thompson.
Bar Harbor, Me	1-10, 000	1, 2, 3, and 4. W. H. Knight.
Rockland Harbor, Me	1-20, 000	2. H. C. Evans. 4. J. G. Thompson and E. H. Sipe.
Isle of Shoals	1-20, 000	4. H. M. Knight.
Salem Harbor, Mass. (new edition)	1-25, 000	4. E. A. Maedel, A. Petersen, J. G. Thompson, W. H. Davis, and W. H. Knight.
Plymouth, Kingston, and Duxbury Harbors, Mass	1-40, 000	3. H. M. Knight. 4. A. Petersen, J. G. Thompson, and E. H. Sipe.
New Haven Harbor, Conn	1-20, 000	4. J. G. Thompson and W. H. Davis.
New York entrance (1875 edition)	1-40, 000	1 and 2. H. C. Evans. 3. H. M. Knight. 4. E. A. Maedel and A. Petersen.
Potomac River, No. 4	1-40, 000	2. A. M. Maedel. 4. A. Petersen.
Whale Branch (inside passage, between Broad and Coosaw Rivers), S. C.	1-40, 000	2. R. F. Bartle. 4. J. G. Thompson and E. H. Sipe.
Doboy and Altamaha Sounds, Ga	1-40, 000	4. A. Petersen.
Horn Island Pass, Miss. (new edition)	1-40, 000	1 and 2. W. A. Thompson. 4. A. Petersen.
San Francisco Bay entrance, Cal. (new edition)	1-50, 000	2 and 3. W. A. Thompson. 4. A. Petersen.
Saint George Reef and Crescent City, Cal	1-40, 000	4. J. G. Thompson.
Yaquina River entrance, Oreg	1-20, 000	3. H. M. Knight. 4. F. Courtenay.
CONTINUED.		
General coast-charts.		
No. V, from Cape Henry, Va., to Cape Lookout, N. C	1-400, 000	4. A. Petersen.
No. XIII, from Cape San Blas to Mississippi Passes	1-400, 000	4. E. A. Maedel and W. H. Davis.
Coast-charts.		
No. 3, Frenchman's and Blue Hill Bays, Me	1-80, 000	1 and 2. J. Enthoffer. 4. E. A. Maedel.
No. 4, Penobscot Bay, Me	1-80, 000	1 and 2. J. Enthoffer. 4. E. A. Maedel, A. Petersen, and J. C. Thompson.
No. 6, Kennebec entrance to Saco River, Me	1-80, 000	2. W. A. Thompson. 3. H. M. Knight. 4. E. A. Maedel.
No. 13, Cuttyhunk to Block Island, including Narragansett Bay.	1-80, 000	1 and 2. J. Enthoffer. 3. H. M. Knight. 4. E. A. Maedel and A. Petersen.
No. 20, New York Bay and Harbor	1-80, 000	1 and 2. W. A. Thompson. 3. H. M. Knight. 4. J. G. Thompson and H. M. Knight.
No. 43, Pamplico Sound, N. C. (middle sheet)	1-80, 000	1 and 2. W. A. Thompson. 4. F. Courtenay.
No. 87, Pensacola entrance, Fla., to Mobile entrance, Ala	1-80, 000	1 and 2. A. Sengteller.
No. 91, Lakes Borgne and Pontchartrain, La	1-80, 000	3. H. M. Knight.
No. 106, Oyster Bay to Matagorda Bay, Tex	1-80, 000	4. A. Petersen.
No. 107, Matagorda Bay, Tex	1-80, 000	2 and 3. H. M. Knight. 4. F. Courtenay, E. A. Maedel, J. G. Thompson, and W. H. Davis.
No. 108, Pass Cavallo and San Antonio Bay, Tex	1-80, 000	2. R. F. Bartle. 3. H. M. Knight. 4. F. Courtenay and W. H. Davis.
No. 109, Aransas and Capano Bays, Tex	1-80, 000	2. R. F. Bartle.
Pamplico River, N. C. (1874 edition)	1-80, 000	1 and 2. H. M. Knight.

APPENDIX No. 5—Continued.

Title of plates.	Scale.	Engravers.
Harbor-charts—CONTINUED.		
Frenchman's Bay, Me	1-40, 000	1. W. A. Thompson. 2. J. Enthoffer. 4. A. Petersen.
Blue Hill Bay, Me	1-40, 000	1. E. Molkow and W. A. Thompson. 2. J. Enthoffer. 4. A. Petersen.
Isle au Haut Bay and Eggemoggin Reach, Me	1-40, 000	1. E. Molkow and W. A. Thompson. 4. A. Petersen.
Penobscot River and Belfast Bay, Me	1-40, 000	1. E. Molkow, W. A. Thompson, and J. G. Thompson. 4. A. Petersen and J. G. Thompson.
Penobscot Bay, Me	1-40, 000	1. W. A. Thompson. 3. H. M. Knight. 4. J. G. Thompson and F. Courtenay.
Albemarle Sound, N. C	1-200, 000	1 and 2. A. M. Maedel.
Beaufort Harbor, N. C	1-40, 000	2. R. F. Bartle. 3. H. M. Knight. 4. W. H. Davis, A. Petersen, and E. H. Sipe.
Core Sound and Straits, N. C	1-40, 000	1, 3, and 4. E. H. Sipe.
Columbia River, No. 2, Oreg	1-40, 000	4. W. H. Davis.
COMMENCED.		
Sailing-chart.		
Atlantic coast, from Cape Sable, Me., to Cape Hatteras, N. C.	1-1, 200, 000 1-400, 000 1-80, 000	1 and 2. W. A. Thompson. 4. J. G. Thompson.
Coast-charts.		
No. 22, from the head of Barnegat Bay to Absecum light, N. J.	1-80, 000	1 and 2. H. C. Evans. 4. E. A. Naedel.
No. 95, Mississippi River, from the Forts to New Orleans, La.	1-80, 000	1. A. Sengteller.
No. 104, Galveston Bay and approaches, Tex	1-80, 000	1 and 2. R. F. Bartle. 4. J. G. Thompson.
Harbor-charts.		
Richmond's Island Harbor, Me. (new edition)	1-20, 000	3. H. M. Knight. 4. A. Petersen and H. M. Knight.
Lake Champlain, No. I (Rouse's Point to Cumberland Head).	1-40, 000	1. J. G. Thompson. 2. H. C. Evans. 4. F. Courtenay.
Lake Champlain, No. II (Cumberland Head to Ligonier Point)	1-40, 000	1. J. G. Thompson. 2. H. C. Evans. 4. F. Courtenay and E. A. Maedel.
Lake Champlain No. III (Burlington to Coles Bay)	1-40, 000	1 and 2. H. C. Evans.
Lake Champlain, No. IV (Coles Bay to Whitehall)	1-40, 000	1 and 2. W. A. Thompson.
Tampa Bay entrance, Fla	1-40, 000	1 and 4. E. H. Sipe.
San Francisco Bay entrance, Cal	1-40, 000	1. E. Molkow.

APPENDIX No. 6.

A NEW SYSTEM OF BINARY ARITHMETIC, BY BENJAMIN PEIRCE, CONSULTING GEOMETER, UNITED STATES COAST SURVEY.

CAMBRIDGE, *February* 25, 1876.

DEAR SIR: In sending you the inclosed paper upon a new system of binary arithmetic, I have no such extravagant thought as that of a substitute for our decimal system. I presume, however, that it is not unsafe to follow in the footsteps of Leibnitz, even in his excursions of pleasure. It seems to me, also, that it may be interesting to compute some of the fundamental numbers of science by a new arithmetic, for the purpose of comparison and verification.

Yours, very truly,

BENJAMIN PEIRCE.

CARLILE P. PATTERSON,
Superintendent United States Coast Survey.

1. Leibnitz proposed a system of binary arithmetic which he thought to be peculiarly fitted to exhibit the symmetry of certain arithmetical operations. Misled by erroneous reports, he believed that a similar system was originally used by the Chinese, as long as two thousand years before the Christian era.

2. The system here proposed retains the advantages of that of Leibnitz, while it is more economical of space, more so even than our ordinary decimal arithmetic. It admits of ready transformation into any other system of which the base is some power of two.

3. In the new system, as in that of Leibnitz, there are only two elementary characters, a vertical straight line and a circle, but their mode of use is interchanged. Leibnitz adopted the ordinary mode of ciphering, in which the circle, called the cipher, occupies each vacant space, while the vertical line is the only significant digit, and represents unity. In the new system, on the contrary, the straight line denotes zero, and occupies each vacant space, while the circle is the significant digit, and stands for unity.

4. The places in the arithmetic of Leibnitz proceed continuously from right to left, as in ordinary arithmetic. But in the proposed system each odd place has, written above it, the next higher even place. Two such successive places constitute a *pair*, and the pairs succeed each other regularly from right to left.

5. Leibnitz required only two forms of type, corresponding to his two characters. But the new system involves three different forms of types, conforming to three different forms of the pairs. The circles, which represent unity, must be small enough to be written over each other, so that they are naturally reduced to a size such that the width of space occupied by a pair will be only hal that of the ordinary figure. The three different form of pair are | ! :, and there is also ¡, which is the inversion of the second form.

6. Leibnitz proposes no nomenclature for his arithmetic, without which it is practically useless. In the new system, it is proposed to call each combination of two successive pairs, of which the right hand is an odd pair, a *quadrate*. There are, then, sixteen (or in the new system *onety*) distinct quadrates, of which the names and numerical representatives are as follows:

zero = | | = |, four = ! |, eight = ¡ |, douze = : |
one = | ! = !, five = ! !, nine = ¡ !, treize = ! :
two = | ¡ = ¡, six = ! ¡, ten = ¡ ¡, quorze = : ¡
three = | : = :, seven = ¡ :, onze = ¡ :, quinze = : :

The successive places of the quadrates, counting from the right, are called *units*, *ties*, *tries*, *quads*, *quints*, *sies*, *septs*, and *octs*, which eight places constitute an *octad*. Each successive octad is divided into two parts, each of which consists of four quadrates. The right division of the octad is distinguished by the termination *illion*, and the left moiety by the termination illiad. The right hand divisions of the octads are thus named, successively, *illions*, *billions*, trillions, and so on, while the left-hand divisions are named illiads, billiads, *trilliads*, and so on. In the case of very high

numbers, however, and especially when the lower portion does not require to be designated, the Greek letter η may be placed after the numbers of the octade, with an exponent m, which shall express the place of the octade, and which shall be designated in enunciation, whether second, third, &c. This latter system corresponds to that adopted by Archimedes in his Arenarius.

7. The number

$$2^{m}-2^{m-1}=2^{m-1}=\text{¡}^{m}-\text{¡}^{m-1}=\text{¡}^{m-1}$$

is written with only one significant digit in the m^{th} place.

8. The number

$$2^{m}-2^{n}=\text{¡}^{m}-\text{¡}^{n}$$

in which

$$m>n$$

consists of $m-n$ significant digits placed in continuous order, of which the highest digit occupies the m^{th} place, and the lowest digit the $n+\text{!}^{\text{st}}$ place.

9. Hence it follows that every number can be expressed in the form

$$\text{¡}^{m}-\text{¡}^{n}+\text{¡}^{m'}-\text{¡}^{n'}+\text{¡}^{m''}-\text{¡}^{n''}+\text{\&c.},$$

in which

$$m>n>m'>n'>m''>n''>, \text{\&c.},$$

and where m, m', m'', &c., correspond to the highest places of the successive groups of continuous digits, and n, n', n'', &c., to the highest places of the successive groups of continuous zeros.

10. In multiplication, we have

$$(\text{¡}^{m}-\text{¡}^{n})\,(\text{¡}^{m'}-\text{¡}^{n'})=\text{!}^{m+m'}-\text{¡}^{m+n'}-\text{¡}^{m'+n}+\text{¡}^{n+n'}$$
$$=\text{¡}^{m+m'}-\text{¡}^{m+n'+\text{!}}+\text{¡}^{m+n'}-\text{¡}^{m'+n}+\text{¡}^{n+n'},$$

in which we may assume

$$m>n \qquad m'>n' \qquad m-n>m'-n'$$

so that the product is a number of which the highest unit occupies the $m+m'^{\text{th}}$ place, and is the first of $m'-n'-\text{!}$ continuous units, at the rate of which is a single vacancy, followed by $(m-n)-(m'-n')$ successive units, and afterward by $m'-n'-\text{!}$ vacancies, and lastly a unit in the $m+n'+\text{!}^{\text{st}}$ place. This proposition supplies the place of a large multiplication-table. A skillful arithmetician will readily apply the principle upon which it is founded to facilitate multiplication and division.

11. Whenever a given number is divided into sets of m places, beginning at the right, it is evident that the sum of these sets divided by the number

$$\text{¡}^{n}-\text{!}$$

gives the same remainder as the number itself when divided by this divisor; and if the remainder is zero, the given number is divisible by the proposed divisor. The principle of this proposition is that which in ordinary arithmetic justifies the casting out of the nines. This divisor consists wholly of units.

12. Whenever the difference of the sum of the first, third, &c., sets of the preceding article—*i. e.* of the uneven sets and of the sum of the even sets—vanishes or is divisible by

$$\text{¡}^{n}+\text{!},$$

the given number is also divisible by this divisor. The principle of this proposition is identical with that of the criterion in ordinary arithmetic for divisibility by eleven. The divisor of this article consists of two units separated by $n-\text{!}$ zeros.

13. The well-known expression of a perfect number becomes in this arithmetic $\text{¡}\,\text{¡}^{n+\text{!}}-\text{¡}^{n}$ in which $\text{¡}^{n+\text{!}}-\text{!}$ must be a prime number.

This requires that $n+\text{!}$ should be a prime number, although this condition is not generally sufficient.

14. Were this arithmetic to be much used, which is quite improbable, the forms of the figures would undoubtedly become more flowing. They might come to resemble the present 6, 9, and 8, or they might assume the character of the Greek φ, or the circles might simply degenerate into crooks, more or less sharp, according to the peculiarity of the writer. But these variations would readily be understood, and would not embarrass the reader.

APPENDIX No. 7.

A CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

The following catalogue supersedes the "*List of Stars for Observations of Latitude*," printed as an Appendix to the Coast Survey Report for 1873, by giving declinations as accurate as obtainable, and right ascensions to the nearest second. It thus furnishes the means of computing at once the results of observations for latitude without waiting for the collating of various astronomical catalogues in order to deduce the best obtainable declinations for the stars observed. For the purpose of a finished reduction it will always be advisable to make such collation, as more recent observations, or the discussions now in progress of systematic errors in existing Star Catalogues, may serve to correct the places contained in the present catalogue, from which, however, very satisfactory results will be obtained.

It has been the custom heretofore in the Coast Survey to select from the British Association's Catalogue the pairs of stars suitable for the determination of latitude, by the method of observing equal meridian zenith-distances with the zenith-telescope. The numbers of the stars so selected for observation at any station were sent to the office, where the mean declinations for the year of observation were obtained by reference to all recent catalogues of precision, comprising the several Greenwich Catalogues, the Washington Observations, the Radcliffe and Armagh, and, where these failed, the Rumker Catalogue. For stars not found in at least two of these catalogues, and those which exhibited large discrepancies in position, express observations were made, by request, at the observatories at Washington and Cambridge.

This practice of deducing the declinations of stars from observations made with different circles and under varied circumstances has led to a great degree of precision in the assumed declinations. The stars used in the method of equal zenith-distances comprise those down to the sixth magnitude, most of which have not been the object of precise determination as standard stars. Still we find that the probable error of the declination of a star derived in the manner above mentioned does not exceed $\pm 0''.3$. And the probable error of one observation with the instruments used being between $0''.3$ and $0''.5$, the observation of sixteen pairs of stars on four nights never fails to reduce the probable error of the latitude below $0''.1$.

The British Association's Catalogue is now very difficult to obtain, and its constants have become obsolete by lapse of time. The continued demand on the office for copies which could not be procured led to the preparation of the catalogue given below, which is intended to replace it as a list of stars available for the observation of latitude by the zenith-telescope in the limits of the United States.

This catalogue comprises all the stars found in the "Bonner Verzeichniss" or "Nördliche Durchmusterung" of Argelander, included in his northern zones and his zone of 1° south declination, and to his sixth magnitude, inclusive.

The list was selected under the direction of Assistant C. S. Peirce, and the names of the stars were assigned by him on the following principles:

1. If the star has a letter assigned by Bayer, it is so designated. If the latitude and longitude correspond with a star of Tycho's Catalogue, this star is considered to be Bayer's. If there was any difficulty in identifying Tycho's star, the identification was guided in several cases by remarks in Argelander's "De fide Uranometriae Bayeri." If the star is not in Tycho it was sought in Ptolemy's Catalogue. In such case the identification with Ptolemy has generally been made through the edition of George of Trebizond, which seems to agree very closely in its readings with the one used by Bayer.

Argelander states that Bayer used the edition of Schreckenfuchs. But the identification of Ptolemy with the heavens is based on Mr. Peirce's transcript of the Paris manuscript, an account of which he has presented to the American Academy of Arts and Sciences. If Bayer's star is neither in Tycho nor Ptolemy, it is then identified by its configuration. The letters thus assigned nearly always agree with those given by Argelander and Baily, except where these authorities differ. In regard to the index numbers attached to a few of the letters, Bayer has been followed as to the number of stars having one letter, and they have been numbered in the order of their right ascension at the epoch of Flamsteed's Catalogue. In cases where Bayer indicates only one star, and his star comprehends two, these have been distinguished as preceding (pr.), and following (sq.), or north (bor.), and south (aust.). The Roman letters are always in Roman type.

In the six constellations where Bayer has a Roman o, this letter and the Greek *ο* are preceded by Flamsteed's numbers.

2. If the star is a variable, it has the letter given it by Schönfeld.

3. If the star has no letter assigned by Bayer or Schönfeld, it is designated by Flamsteed's number, when put by him in the same constellation as by Heis. In identifying Flamsteed's stars the authority of Baily has been followed.

4. If the star is in none of these lists, the Durchmusterung zone and number are given. D. M. is the abbreviation used for Durchmusterung. The *magnitudes* have been reduced to a scale of "equable distribution" according to the methed explained in Mr. Peirce's Photometric Researches, in the Annals of the Harvard College Observatory.

The places of stars given in this catalogue have been prepared, under the immediate direction of Assistant Hilgard, by Assistant O. H. Tittmann, aided by C. Ferguson, H. W. Blair, J. B. Baylor, A. Braid, and A. H. Scott.

The *right ascensions* are given to nearest seconds of time only, as that is amply sufficient for the special purpose of the catalogue. The right ascensions of a great number of stars are found in other catalogues expressly prepared for observations of time, such as the Coast Survey Standard Mean Places of Fundamental Stars, prepared by Dr. B. A. Gould in 1862, and the Field Catalogue of 983 Transit Stars, prepared by Assistant G. Davidson, and published in 1874. Moreover, the American Ephemeris and Nautical Almanac will be generally used for the determination of time, as it gives ready to hand the apparent places of quite a sufficient number of convenient stars.

It is unnecessary to state in detail the process by which the right ascensions and their annual variations have been deduced, as only the nearest second of time is given; the computations, however, were carried to tenths of seconds.

The *declinations* have been deduced by a comparison of all modern catalogues of precision, notably the following, viz:

Greenwich New Seven-Year Catalogue of 2760 Stars, 1864.
Greenwich Seven-Year Catalogue of 2022 Stars, 1860.
Greenwich Six-Year Catalogue of 1576 Stars, 1850.
Greenwich Twelve-Year Catalogue of 2156 Stars, 1836–1847.
Washington Catalogue of Stars, 1845–1871.
Astronomische Gesellschaft (mean and apparent places of 539 Stars for 1878).
Radcliffe Catalogue of 6317 Stars, for the epoch 1845.
Second Radcliffe Catalogue of 2356 Stars, for the epoch 1860.
Armagh Observatory Catalogue. Places of 5345 Stars, observed from 1828 to 1854.
British Association Catalogue of Stars, reduced to the epoch 1850.
Rumker's Catalogue. Mean places of 12000 Stars for the epoch 1836.

This examination has revealed the fact that there are in the northern heavens numerous stars as bright and brighter than the sixth magnitude, whose places have never been determined with precision, and that there are as many as 250 stars in this list that have either never been observed at all with precision, or that are not found in any catalogue more recent than that of the British Association or Radcliffe (1). Such stars are marked with an asterisk (*) in the present catalogue, and a list of them has been furnished to the principal observatories, with the request that their positions be determined with accuracy.

All other stars have been found in one or more of the recent catalogues of precision, and generally with not less than four observations. Nearly two-thirds of their number had been heretofore used for latitude observations in the Coast Survey, and their positions deduced by a comparison of the catalogues above mentioned. This work had been performed in the Computing Division of the office, under the direction of Assistant C. A. Schott, by Mr. James Main, whose methods were followed in deducing the places of the remaining stars. The large number of results for latitude obtained with the use of declinations so deduced justify the statement made above that the average probable error of the declination of a star as here given will not exceed $\pm 0''.3$.

The *annual precession* in declination was computed for every minute of time by the expression

$$\Delta\delta = 20''.054 \cos \alpha$$

and that belonging to any particular star was obtained by interpolation.

The *proper motions* given in the last column were taken from the Coast Survey Catalogue of Fundamental Stars, from the Seven-Year New Greenwich, the Radcliffe (2), and the British Association Catalogues in that order of preference.

The introduction of thirteen stars omitted from the former list, and the transposition of some in order to preserve the order of right ascension, occasions a difference in the serial numbers of the present list as compared with the former, which must now be considered as entirely superseded.

J. E. HILGARD,

Assistant U. S. Coast Survey, in charge of Office.

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1	8373	10 Cassiopeæ	5.5	0 00 13	+ 3.08	63 31 41.5	+ 20.05	+ .01
2	4	α Andromedæ	2.0	2 11	3.09	28 25 41.3	20.05	− .15
3	7	β Cassiopeæ	2.3	2 47	3.17	58 29 16.8	20.05	− .17
4	8	87 Pegasi	5.5	2 51	3.09	17 32 42.5	20.05	+ .02
5	14	34 Piscium	5.7	3 52	3.07	10 28 39.8	20.05	− .05
6	16	22 Andromedæ	5.2	4 05	3.10	45 24 15.5	20.05	...
7	.	Andromedæ	5.6	5 42	3.10	47 29 02.8	20.05	...
8*	.	D. M. 22°, 14	5.8	5 ..	3.09	22 49	20.05	...
9	26	γ Pegasi	2.8	7 03	3.08	14 30 58.9	20.04	+ .00
10	28	23 Andromedæ	6.0	7 17	3.10	40 22 22.5	20.04	− .08
11	32	χ Pegasi	4.9	0 8 24	+ 3.10	19 32 21.6	+ 20.04	+ .02
12*	.	Pegasi	6.0	8 ..	3.09	21 37	20.04	...
13	36	35 Piscium	5.8	8 48	3.08	8 09 15.0	20.04	− .05
14	.	Andromedæ	5.8	10 03	3.11	42 55 44.6	20.04	...
15	46	Cassiopeæ	5.8	10 32	3.20	60 51 58.4	20.03	− .01
16	51	D. M. 47°, 50	6.0	10 49	3.14	47 16 49.3	20.03	...
17	52	ϑ Andromedæ	4.8	10 49	3.11	38 00 55.7	20.03	− .01
18	58	σ Andromedæ	4.4	12 04	3.12	36 07 11.5	20.02	− .04
19	.	Andromedæ	5.8	12 21	3.12	30 51 04.0	20.02	...
20	60	26 Andromedæ	6.0	12 23	3.14	43 07 29.3	20.02	+ .02
21*	.	Andromedæ	5.8	0 14.5	+ 3.13	32 15	+ 20.01	...
22	67	ρ Andromedæ	5.4	14 48	3.15	37 18 16.2	20.01	− .02
23	79	Cassiopeæ	5.8	17 48	3.20	51 21 17.5	19.99	...
24	83	Cassiopeæ	5.8	18 37	3.21	52 22 53.9	19.99	− .03
25	100	Andromedæ	5.4	21 47	3.19	43 43 51.0	19.96	− .01
26	101	47 Piscium	5.3	21 48	3.12	17 13 43.2	19.96	+ .11
27	102	48 Piscium	5.8	21 59	3.11	15 46 54.5	19.96	+ .01
28*	..	Cassiopeæ	5.8	23.7	3.30	59 18	19.95	...
29	109	28 Andromedæ	5.5	23 48	3.15	29 05 23.8	19.95	− .07
30	120	Andromedæ	5.8	25 03	3.17	32 55 09.2	19.93	...
31	121	λ Cassiopeæ	5.1	0 25 10	+ 3.28	53 51 34.7	+ 19.93	+ .02
32	126	κ Cassiopeæ	4.5	26 11	3.36	62 16 10.3	19.92	+ .02
33	130	52 Piscium	5.4	26 18	3.14	19 38 00.5	19.92	− .03
34	142	D. M. 12°, 57	5.8	28 42	3.11	12 42 43.0	19.90	+ .03
35	147	14 Ceti	5.9	29 23	3.08	− 1 09 56.2	19.89	− .14
36	146	Cassiopeæ	5.7	29 28	3.31	53 30 26.1	19.89	+ .04
37	148	Cassiopeæ	5.8	29 39	3.36	59 39 54.5	19.89	.00
38	152	Andromedæ	5.3	30 15	3.24	43 49 34.8	19.88	+ .01
39	153	ζ Cassiopeæ	3.8	30 17	3.31	53 14 11.2	19.88	+ .01
40	155	π Andromedæ	4.2	30 28	3.19	33 03 31.3	19.88	+ .02
41*	..	Andromedæ	6.0	0 30.8	+ 3.15	23 21	+ 19.87	...
42	158	Andromedæ	5.7	30 56	3.20	34 44 20.1	19.87	− .04
43	164	ε Andromedæ	4.4	32 13	3.15	28 39 37.2	19.85	− .24
44	165	Cassiopeæ	5.6	32 32	3.29	48 41 40.4	19.85	...
45	166	δ Andromedæ	3.5	32 55	3.19	30 12 14.0	19.84	− .11
46	170	55 Piscium	5.4	33 37	3.15	20 46 48.0	19.84	− .01
47	169	α Cassiopeæ	var. 2.5–2.8	33 42	3.37	55 52 44.1	19.84	− .03
48	173	32 Andromedæ	5.1	34 37	3.25	38 48 00.3	19.82	+ .02
49	175	Cassiopeæ	6.0	34 55	3.52	65 29 21.1	19.82	...
50	178	Andromedæ	6.0	35 15	3.20	23 58 16.3	19.82	+ .02

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
51	180	ξ Cassiopeæ	5.1	0 35 23	+ 3.32	49 51 13.7	+ 19.82	− .05
52	189	π Cassiopeæ	5.3	36 50	3.30	46 22 05.6	19.79	− .01
53	194	21 Cassiopeæ	5.5	37 45	3.84	74 19 54.0	19.78	− .06
54	197	Cassiopeæ	6.0	37 46	3.30	47 12 22.3	19.78	...
55	198	ο Cassiopeæ	5.0	38 03	3.32	47 37 39.1	19.78	− .03
56	201	Cassiopeæ	5.7	38 28	3.40	54 33 49.3	19.78	− .08
57	206	23 Cassiopeæ	5.5	39 47	3.89	74 11 29.3	19.75	− .04
58	211	57 Piscium	5.1	40 16	3.13	14 49 14.3	19.74	− .04
59	213	58 Piscium	5.0	40 46	3.12	11 19 11.6	19.74	+ .06
60	215	ζ Andromedæ	4.3	40 59	3.17	23 36 51.0	19.73	− .07
61	218	η Cassiopeæ	3.5	0 41 51	+ 3.58	57 10 43.8	+ 19.72	− .49
62	219	ν Cassiopeæ	5.1	42 02	3.37	50 18 46.5	19.72	− .07
63	221	Piscium	5.8	42 05	3.13	4 39 47.4	19.72	−1.18
64	222	δ Piscium	4.4	42 27	3.11	6 55 54.6	19.71	− .05
65	223	64 Piscium	5.5	42 40	3.14	16 17 33.4	19.71	− .16
66	227	ν Andromedæ	4.9	43 12	3.28	40 25 30.7	19.70	− .01
67	229	i Piscium, (1st *)	5.3	43 26	3.21	27 03 24.4	19.69	+ .03
68	228	Cassiopeæ	5.7	43 27	3.58	63 35 36.9	19.69	− .03
69	239	Cassiopeæ	5.1	45 55	3.53	60 27 52.5	19.63	+ .05
70	242	20 Ceti	5.0	46 52	3.06	− 1 47 45.7	19.63	− .01
71	244	υ¹ Cassiopeæ	5.0	0 47 53	+ 3.51	58 19 20.1	+ 19.62	− .09
72	247	66 Piscium	5.8	48 14	3.16	18 32 17.3	19.61	+ .04
73	250	36 Andromedæ	5.9	48 33	3.20	22 58 42.9	19.61	.00
74	253	γ Cassiopeæ	2.1	49 29	3.57	60 03 59.0	19.59	+ .02
75*	256	k Piscium	5.8	49 32	3.22	26 33 30.0	19.59	+ .08
76	254	υ² Cassiopeæ	5.0	49 32	3.53	58 31 58.0	19.59	...
77	259	μ Andromedæ	4.1	50 06	3.30	37 50 54.3	19.58	+ .05
78	264	η Andromedæ	4.5	50 48	3.19	22 46 09.1	19.56	+ .01
79*	261	Cassiopeæ	5.8	50 56	3.72	65 42 11.3	19.56	.00
80	267	h Piscium	5.8	51 21	3.23	28 20 35.7	19.55	− .01
81	269	Piscium	5.8	0 51 37	+ 3.14	13 02 48.0	+ 19.55	− .05
82	262	Cephei	4.7	52 36	7.10	85 36 44.1	19.53	.00
83	283	39 Andromedæ	6.3	56 10	3.35	40 41 59.2	19.45	...
84*	285	σ Piscium	5.3	56 15	3.27	31 09 37.0	19.44	...
85	288	ε Piscium	4.2	56 43	3.11	7 14 37.3	19.44	+ .03
86*	..	Cassiopeæ	6.0	56 56	3.66	60 56	19.44	...
87*	..	D. M. 51°, 220	5.8	57 ..	3.49	51 51	19.44	...
88	295	26 Ceti (N. star)	6.0	57 38	3.08	0 43 22.2	19.42	− .07
89	303	73 Piscium	6.0	58 40	3.11	5 00 46.4	19.40	− .02
90	305	72 Piscium	5.6	58 45	3.16	14 18 01.4	19.40	+ .05
91	307	ψ_1 Piscium (pr.)	4.9	0 59 15	+ 3.21	20 49 48.9	+ 19.39	− .02
92	308	ψ_1 Piscium (sq.)	5.8	59 16	3.21	20 49 20.9	19.39	− .03
93	314	μ Cassiopeæ	5.3	1 00 18	3.93	54 19 51.0	19.36	−1.55
94	318	41 Andromedæ	5.3	01 08	3.42	43 18 08.9	19.35	− .04
95	322	ψ_2 Piscium	5.5	01 31	3.21	20 06 01.4	19.34	− .10
96	320	Cephei	5.4	1 01 57	4.91	79 02 03.3	19.32	...
97	328	e Piscium	5.5	02 11	3.08	5 00 52.3	19.32	− .19
98	330	φ Andromedæ	4.5	02 32	3.45	46 36 05.8	19.31	+ .02
99	327	31 Cassiopeæ	5.8	02 33	3.97	68 08 23.0	19.31	− .01
100	334	β Andromedæ	2.4	03 01	3.34	34 59 02.9	19.30	− .09

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B.A.C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
101	336	ψ_3 Piscium	5.5	1 03 25	+ 3.21	19 01 14.2	+ 19.29	.00
102*	335	Cassiopeæ	5.8	03.7	3.81	63 34	19.28	...
103	339	ϑ Cassiopeæ	4.6	03 48	3.61	51 30 40.4	19.28	...
104*	..	Piscium	5.8	03.8	3.24	24 50	19.28	...
105	338	32 Cassiopeæ	5.8	03 53	3.78	64 22 48.8	19.28	− .01
106	344	33 Ceti	6.0	04 23	3.08	1 48 23.6	19.27	− .02
107	343	45 Andromedæ	5.8	04 25	3.31	37 05 08.5	19.27	+ .06
108	345	g Piscium	5.3	04 30	3.30	30 47 08.2	19.26	− .03
109	348	χ Piscium	4.6	05 00	3.21	20 23 45.9	19.25	− .01
110	349	τ Piscium	4.2	05 03	3.29	29 27 07.6	19.25	− .03
111	365	φ Piscium	4.5	1 07 14	+ 3.25	23 56 54.0	+ 19.20	+ .03
112	368	ζ Piscium (1st *)	4.9	07 28	3.13	6 56 24.8	19.19	− .06
113	363	Cassiopeæ	6.0	07 36	4.20	71 06 29.9	19.19	+ .02
114	374	38 Ceti	5.7	08 41	3.05	− 1 36 58.0	19.16	+ .21
115	388	f Piscium	5.2	11 36	3.09	2 58 56.5	10.08	− .02
116	395	υ Piscium	4.5	12 52	3.28	26 37 58.9	19.06	+ .05
117	393	Cephei	5.8	13 16	5.08	78 05 48.6	19.04	...
118	400	42 Ceti	5.8	13 40	3.07	− 1 08 22.5	19.02	− .01
119	401	l Piscium	4.9	14 29	3.30	28 06 39.7	19.00	− .05
120	360	α Ursæ Minoris	2.1	14 46	21.64	88 40 08.9	18.99	.00
121	404	ξ Andromedæ	4.9	1 15 17	+ 3.50	44 53 57.7	+ 18.98	− .01
122	409	47 Andromedæ	5.8	16 49	3.42	37 05 17.9	18.94	+ .02
123	412	ψ Cassiopeæ	5.0	17 28	4.15	67 30 10.3	18.92	+ .02
124	416	δ Cassiopeæ	2.7	17 59	3.87	59 36 39.4	18.90	− .04
125	425	Andromedæ	6.2	19 16	3.50	42 50 05.4	18.86	− .04
126	427	ρ Piscium	5.1	19 47	3.22	18 32 49.3	18.85	+ .02
127	431	94 Piscium	5.8	20 13	3.23	18 37 06.2	18.84	− .01
128	432	ω Andromedæ	5.1	20 29	3.56	44 47 11.8	18.83	− .10
129*	..	D. M. 40°, 289	5.8	20.5	3.47	40 29	18.83	...
130*	..	Cassiopeæ	6.0	22.5	4.11	65 29	18.77	...
131	441	Andromedæ	5.5	1 22 54	+ 3.56	46 23 15.9	+ 18.75	− .03
132	448	μ Piscium	4.9	23 54	3.14	5 31 26.7	18.72	− .18
133	453	η Piscium	3.9	25 04	3.20	14 43 37.0	18.69	+ .02
134	456	χ Cassiopeæ	5.6	26 06	3.87	58 36 55.6	18.65	− .03
135	468	40 Cassiopeæ	5.2	28 57	4.66	72 25 39.5	18.56	+ .02
136	480	υ Andromedæ	4.3	29 46	3.49	40 48 17.3	18.54	− .37
137	482	Cassiopeæ	5.8	30 17	3.87	57 21 55.7	18.52	...
138	487	υ Persei	3.8	30 38	3.65	48 01 10.5	18.51	− .14
139	488	π Piscium	5.6	30 44	3.17	11 31 38.6	18.50	+ .03
140	492	χ Andromedæ	5.2	32 09	3.57	43 46 30.3	18.45	...
141	501	Andromedæ	5.9	1 33 28	+ 3.56	42 41 25.8	+ 18.41	...
142	502	τ Andromedæ	5.6	33 30	3.52	39 58 05.5	18.41	− .09
143	499	42 Cassiopeæ	5.6	33 39	4.55	70 00 54.5	18.40	− .02
144	510	Andromedæ	5.2	34 29	3.63	42 00 40.2	18.37	− .06
145*	..	D.M. 25°, 276	5.8	34.6	3.32	25 08	18.37	...
146	514	Trianguli	5.8	34 53	3.37	29 26 24.2	18.36	+ .14
147	516	Trianguli	5.8	35 08	3.45	34 38 22.6	18.35	...
148	518	ν Piscium	4.7	35 11	3.12	4 52 47.0	18.35	− .04
149	515	44 Cassiopeæ	5.7	35 13	4.02	59 56 42.2	18.35	− .03
150	523	107 Piscium	5.3	35 59	3.25	19 41 05.1	18.32	− .66

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
151	522	φ Persei	4.5	1 36 09	+ 3.73	50 05 00.1	+ 18.31	− .03
152	537	ο Piscium	4.3	39 04	3.16	8 33 11.4	18.21	+ .04
153	544	D. M. 37°, 372	5.8	41 34	3.51	37 21 17.5	18.12	+ .01
154	546	4 Arietis	5.8	41 40	3.25	16 21 28.2	18.11	+ .04
155	556	1 Arietis	5.8	43 31	3.31	21 40 44.4	18.04	+ .09
156	558	1 Persei	5.6	44 07	3.90	54 33 07.1	18.02	− .05
157	561	Arietis	5.6	44 30	3.17	10 26 54.0	18.00	− .07
158	564	ε Cassiopeæ	3.4	45 47	4.25	63 04 41.7	17.96	...
159	566	55 Andromedæ	5.6	46 05	3.57	40 08 11.5	17.94	− .05
160	569	α Trianguli	3.5	46 15	3.40	28 59 37.3	17.94	− .21
161	568	ω Cassiopeæ	5.1	1 46 42	+ 4.56	68 05 40.3	+ 17.92	− .03
162	572	γ Arietis (North Star)	3.8	46 57	3.28	18 42 17.5	17.91	− .11
163	574	ξ Piscium	4.3	47 21	3.10	2 35 39.1	17.89	− .08
164	577	β Arietis	2.6	48 01	3.30	20 13 15.2	17.87	− .09
165	579	56 Andromedæ (pr.)	5.8	48 49	3.54	36 41 19.4	17.84	+ .01
166	580	56 Andromedæ (sq.)	5.8	49 02	3.54	36 39 45.5	17.83	+ .04
167	592	ι Arietis	5.5	50 48	3.26	17 13 52.7	17.76	− .04
168	588	Cassiopeæ	5.8	50 48	4.35	64 02 12.3	17.76	...
169	593	λ Arietis	4.9	51 13	3.33	23 00 36.1	17.74	...
170	595	A Cassiopeæ	4.6	52 08	4.83	70 19 26.0	17.70	− .01
171	597	47 Cassiopeæ	5.1	1 53 09	+ 5.78	76 42 12.1	+ 17.66	− .02
172	600	50 Cassiopeæ	4.1	53 13	4.99	71 50 22.1	17.66	.00
173	610	52 Cassiopeæ	5.8	53 57	4.40	64 19 15.5	17.62	− .02
174	608	49 Cassiopeæ	5.1	54 06	5.54	75 32 13.2	17.62	+ .02
175	611	53 Cassiopeæ	5.9	54 08	4.37	63 48 35.0	17.62	+ .02
176	614	4 Persei	4.9	54 19	3.95	53 54 23.7	17.61	+ .01
177	625	α Piscium (sq.)	3.6	55 50	3.09	2 11 00.3	17.55	− .02
178	624	ε Trianguli	5.5	55 58	3.49	32 42 18.4	17.54	...
179	628	γ Andromedæ	2.2	56 32	3.65	41 45 10.8	17.52	− .06
180	630	10 Arietis	5.7	56 51	3.39	25 21 22.2	17.50	− .03
181	633	60 Ceti	5.7	1 57 02	+ 3.08	− 0 27 02.5	+ 17.50	− .02
182	644	κ Arietis	5.5	59 51	3.35	22 04 32.9	17.38	+ .04
183	648	α Arietis	2.2	2 00 25	3.37	22 53 39.7	17.35	− .13
184	649	58 Andromedæ	5.0	01 15	3.60	37 17 21.2	17.31	− .03
185	653	Persei	5.8	02 05	3.95	53 16 31.1	17.28	− .02
186	656	β Trianguli	3.1	02 24	3.55	34 25 08.3	17.26	− .05
187	657	14 Arietis	4.9	02 36	3.40	25 22 15.3	17.25	− .08
188	665	15 Arietis	5.7	03 59	3.31	18 56 00.8	17.19	− .05
189	668	55 Cassiopeæ	6.1	05 05	4.62	65 57 38.8	17.14	.00
190	675	6 Trianguli (1st star)	5.0	05 25	3.47	29 44 23.9	17.13	− .05
191	676	b Andromedæ	4.9	2 05 42	+ 3.74	43 40 04.0	+ 17.11	− .04
192	682	η Arietis	5.4	06 05	3.34	20 38 47.0	17.09	+ .01
193	683	19 Arietis	5 7	06 31	3.26	14 43 00.8	17.07	− .02
194	684	ξ¹ Ceti	4.5	06 38	3.17	8 16 58.7	17.07	− .01
195	691	7 Trianguli	5.2	08 51	3.53	32 48 01.6	16.97	− .01
196	693	21 Arietis	5.7	08 54	3.39	24 29 09.5	16.96	− .07
197	697	δ Trianguli	5.0	09 44	3.64	33 40 27.7	16.93	− .25
198	698	γ Trianguli	4.2	10 11	3.55	33 17 30.4	16.90	− .02
199	707	ϑ Arietis	5.7	11 27	3.33	19 20 42.9	16.84	− .01
200	706	c Andromedæ	5.6	11 33	3.84	46 49 31.2	16.84	− .02

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
201	708	Ceti	5.7	2 11 47	+ 3.10	1 11 22.6	+ 16.83	+ .36
202	710	10 Trianguli	5.4	12 00	3.47	28 05 17.1	16.82	...
203*	. .	Arietis	6.0	12.2	3.77	22 37	16.81	...
204	721	i Persei	5.4	14 00	4.13	55 17 44.1	16.82	...
205	729	69 Ceti	5.5	15 48	3.07	− 0 09 12.7	16.63	− .05
206	732	70 Ceti	5.5	16 06	3.05	− 1 25 54.7	16.62	− .03
207	731	64 Andromedæ	5.4	16 27	3.95	49 27 39.9	16.60	− .05
208	735	65 Andromedæ	4.9	17 38	3.97	49 44 02.7	16.55	− .06
209	745	ξ Arietis	5.3	18 23	3.20	10 03 57.3	16.51	− .05
210†	744	ι Cassiopeæ	4.4	19 12	4.85	66 51 40.8	16.47	− .02
211	752	11 Trianguli	5.5	2 20 21	+ 3.53	31 15 42.8	+ 16.41	− .02
212	757	12 Trianguli	5.3	21 08	3.50	29 07 57.8	16.37	− .09
213	760	ξ^2 Ceti	4.3	21 47	3.18	7 55 16.7	16.33	− .02
214*	. .	Arietis	5.8	22.4	3.40	22 56	16.30	...
215	772	14 Trianguli	5.4	24 47	3.64	35 36 49.7	16.18	− .01
216	776	Ceti	5.6	25 18	3.09	1 44 05.8	16.16	...
217	778	75 Ceti	5.5	26 03	3.05	− 1 33 56.4	16.12	− .06
218	777	115 Cassiopeæ	5.1	26 39	5.57	72 17 30.1	16.09	+ .01
219	. .	Persei	5.8	28 15	3.67	36 47 10.2	16.00	.00
220	786	15 Trianguli	5.4	28 30	3.62	34 09 47.0	15.99	− .04
221	794	ν Ceti	5.0	2 29 35	+ 3.14	5 04 07.5	+ 15.93	− .03
222	798	31 Arietis	5.1	30 05	3.26	11 55 35.2	15.91	− .09
223	784	Cephei	5.7	30 35	8.21	80 56 16.6	15.88	.00
224	808	ν Arietis	5.5	32 00	3.39	21 26 29.8	15.80	− .02
225	811	δ Ceti	3.9	33 20	3.07	− 0 11 24.7	15.73	− .03
226	813	33 Arietis	5.3	33 40	3.49	26 32 43.3	15.71	+ .01
227	816	11 Persei	5.8	34 28	4.25	54 35 33.1	15.67	− .03
228	819	Persei	6.0	34 32	4.18	53 00 47.6	15.66	...
229	821	12 Persei	5.1	34 41	3.76	39 41 08.3	15.66	− .18
230	825	μ Arietis	5.6	35 36	3.37	19 29 57.4	15.61	− .01
231	827	ϑ Persei	4.3	2 36 00	+ 4.06	48 43 09.8	+ 15.58	− .10
232	829	14 Persei	5.7	36 17	3.89	43 47 08.6	15.57	− .01
233	831	35 Arietis	4.9	36 25	3.50	27 11 44.1	15.56	+ .02
234	837	γ Ceti	3.4	37 05	3.10	2 43 45.3	15.52	− .15
235	842	ο Arietis	5.8	37 56	3.30	14 48 08.9	15.48	− .07
236	844	38 Arietis	4.9	38 25	3.26	11 56 23.1	15.45	− .10
237	845	μ Ceti	4.1	38 27	3.23	9 36 22.8	15.45	− .05
238	861	39 Arietis	4.9	40 46	3.55	28 44 52.9	15.32	− .11
239	866	Arietis	5.7	41 47	3.48	24 41 11.3	15.26	− .01
240	867	40 Arietis	6.0	41 49	3.35	17 46 57.3	15.26	− .02
241	863	η Persei	4.3	2 41 57	+ 4.33	55 23 46.4	+ 15.25	...
242	870	π Arietis	5.4	42 36	3.34	16 57 52.6	15.21	+ .02
243	872	41 Arietis	3.7	42 55	3.51	26 45 53.4	15.20	− .13
244	871	16 Persei	4.6	43 01	3.76	37 49 26.1	15.19	− .07
245*	. .	Persei	6.0	43.7	3.99	46 21	15.15	...
246	877	17 Persei	4.7	44 07	3.68	34 33 51.8	15.13	− .11
247	881	σ Arietis	5.6	44 52	3.30	14 35 11.4	15.08	− .05
248	885	τ Persei	4.1	45 45	4.21	52 16 12.1	15.04	− .01
249	888	20 Persei	5.6	46 08	3.77	37 50 51.3	15.01	− .07
250*	. .	D. M. 60°, 591	5.8	46.4	4.68	61 02	14.99	...

† Triple.

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
251	897	D. M. 46°, 658 . . .	5.8	2 48 27	+ 4.02	46 40 34.5	+ 14.87	.00
252	901	ρ Arietis (pr.)	6.0	49 04	3.36	17 50 40.3	14.84	+ .01
253	904	21 Persei.	4.9	50 01	3.62	31 26 59.8	14.78	+ .02
254	896	Cephei	5.6	50 12	7.68	78 56 31.0	14.77	+ .01
255	912	π Persei.	4.9	51 05	3.82	39 10 53.3	14.72	− .03
256	913	47 Arietis	5.6	51 13	3.42	20 11 11.2	14.71	− .03
257	915	24 Persei.	5.2	51 38	3.70	34 42 01.5	14.69	− .07
258	914	Persei.	5.7	51 41	4.04	46 44 18.5	14.68	.00
259	918	Persei.	5.3	52 20	4.25	51 52 25.9	14.65	+ .05
260	921	ε Arietis	4.4	52 21	3.42	20 51 34.1	14.65	− .02
261	908	Cephei	5.6	2 53 12	+ 8.82	81 00 11.9	+ 14.59	+ .02
262	929	λ Ceti	4.7	53 17	3.22	8 25 42.5	14.59	− .03
263	941	49 Arietis	5.6	54 50	3.52	25 59 11.2	14.50	− .01
264	949	α Ceti	2.6	56 00	3.13	3 37 04.6	14.43	− .09
265	947	γ Persei.	3.1	56 07	4.30	53 02 06.7	14.42	.00
266	948	k Persei.	4.9	56 32	4.46	56 13 59.2	14.39	+ .08
267*	. .	Cassiopeæ	6.0	57.3	4.95	63 36	14.34	...
268	953	ρ Persei.	var. 3.5–4.0	57 29	3.82	38 22 28.3	14.33	− .08
269	957	52 Arietis	5.6	58 25	3.51	24 47 12.6	14.28	− .03
270	955	Cassiopeæ	5.4	58 58	6.34	73 56 08.4	14.25	− .07
271*	. .	Arietis	5.4	2 59.8	+ 3.29	12 44	+ 14.19	...
272	963	β Persei.	var. 2.3–4.0	3 00 22	3.87	40 29 32.1	14.16	+ .01
273	962	ι Persei.	4.4	00 25	4.30	49 09 13.5	14.16	.00
274	967	κ Persei.	4.0	01 24	4.02	44 24 05.7	14.09	− .15
275	974	55 Arietis	5.8	02 24	3.60	28 37 03.5	14.03	+ .02
276	980	Arietis	6.0	03 20	3.55	26 26 07.9	13.97	...
277	981	ω Persei.	4.8	03 33	3.85	39 09 16.6	13.96	+ .02
278	960	Cephei	5.8	04 08	13.03	84 28 53.5	13.92	− .12
279	986	δ Arietis	4.3	04 46	3.42	19 16 18.4	13.88	.00
280	994	94 Ceti	5.3	06 39	3.06	− 1 38 46.4	13.76	− .08
281*	. .	Persei.	5.8	3 06.6	+ 4.55	56 41	+ 13.77	...
282	995	Persei.	5.3	07 38	4.26	50 29 28.0	13.70	.00
283	999	ζ Arietis	4.6	08 00	3.44	20 35 55.7	13.68	− .07
284*	. .	Persei.	5.7	08 02	3.64	30 06 31.9	13.68	...
285	1001	Camelopardalis . . .	4.6	09 27	5.19	65 12 41.0	13.58	− .03
286	1006	30 Persei.	5.8	09 43	4.01	43 34 57.3	13.57	− .04
287	1007	29 Persei.	5.5	10 05	4.25	49 46 51.4	13.54	− .06
288	1011	31 Persei.	5.5	10 36	4.24	49 39 17.3	13.51	− .04
289	1017	Persei.	4.9	11 14	3.74	33 46 52.3	13.47	− .07
290	1023	59 Arietis	5.8	12 46	3.57	26 38 10.2	13.37	− .02
291	1028	κ Ceti	5.1	3 13 04	+ 3.14	2 55 39.9	+ 13.35	− .02
292	1025	Arietis	5.0	13 06	3.64	28 36 43.5	13.35	− .06
293	1026	l Persei.	5.2	13 24	4.00	42 53 40.3	13.33	− .01
294	1030	Camelopardalis . . .	5.8	14 16	5.15	64 09 15.3	13.27	− .09
295	1034	τ Arietis	4.9	14 18	3.45	20 42 48.0	13.27	− .03
296	1040	62 Arietis	5.5	15 00	3.59	27 10 34.1	13.22	.00
297	1043	α Persei.	2.0	15 46	4.25	49 25 56.5	13.17	− .05
298	1045	63 Arietis	5.0	15 51	3.44	20 18 41.6	13.17	− .02
299*	. .	Persei.	5.6	17 ..	3.73	33 06	13.09	...
300	1052	64 Arietis	5.6	17 13	3.53	24 17 51.3	13.08	− .07

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
301	1053	65 Arietis	5.6	3 17 31	+ 3.45	20 22 35.5	+ 13.06	− .02
302*	. .	Tauri	6.0	17.6	3.29	12 12	13.05	...
303	1057	10 Tauri	3.8	18 21	3.22	8 36 19.9	13.00	− .10
304	1058	Camelopardalis	4.5	19 22	4.81	59 31 14.8	12.93	+ .04
305	1059	Persei	5.4	19 32	4.24	48 38 32.6	12.92	− .06
306	1062	Camelopardalis	4.9	20 20	4.75	58 27 40.2	12.87	+ .03
307	1068	ξ Tauri	3.9	20 40	3.24	9 18 46.8	12.84	− .04
308	1066	34 Persei	5.1	20 47	4.26	49 05 29.5	12.84	− .06
309*	. .	Persei	5.8	20.8	3.75	33 23	12.84	...
310	1065	Camelopardalis	4.8	20 52	4.54	55 02 03.9	12.83	− .12
311	1069	66 Arietis	5.9	3 21 26	+ 3.50	22 23 20.2	+ 12.80	− .14
312	1071	σ Persei	4.6	22 07	4.20	47 34 45.4	12.75	.00
313	1084	s Tauri	5.2	23 51	3.27	10 55 23.9	12.63	− .05
314*	. .	Tauri	5.6	24.1	3.60	27 09	12.62	...
315	1083	36 Persei	5.5	24 08	4.13	45 38 54.6	12.61	− .08
316	1087	f Tauri	4.2	24 15	3.31	12 31 27.6	12.60	− .03
317*	. .	Camelopardalis	6.0	24.5	4.53	54 33	12.58	...
318*	. .	Persei	5.8	25.0	3.80	35 03	12.55	...
319	. .	Persei	5.8	25 41	3.93	39 39 38.8	12.50	...
320	1061	Cephei	5.6	27 38	21.67	86 15 56.3	12.37	...
321	1099	ψ Persei	4.6	3 27 58	+ 4.24	47 47 29.9	+ 12.35	− .04
322	1112	10 Tauri	4.3	30 45	3.06	0 01 10.4	12.16	− .52
323	1111	Camelopardalis	5.3	31 45	5.15	62 49 33.3	12.09	+ .08
324*	. .	Tauri	6.0	32.0	3.47	20 31	12.07	...
325	1119	Tauri	5.8	32 39	3.39	16 08 40.6	12.04	− .06
326*	1117	Camelopardalis	6.0	32 49	4.89	59 35	12.01	...
327	1123	Persei	5.6	33 20	3.91	37 11 30.7	11.98	+ .07
328	1128	12 Tauri	5.8	33 36	3.12	2 39 56.0	11.96	+ .01
329	1129	δ Persei	3.2	34 23	4.24	47 24 08.2	11.90	− .05
330	1132	40 Persei	4.9	34 46	3.79	33 34 43.5	11.87	.00
331	1135	13 Tauri	5.5	3 35 24	+ 3.45	19 18 53.0	+ 11.83	− .01
332	1133	Camelopardalis	5.3	35 33	5.19	62 57 47.1	11.82	− .07
333*	. .	Camelopardalis	5.2	36.8	6.14	70 30	11.73	...
334	. .	Persei	5.6	36 46	3.86	36 04 48.1	11.73	...
335	1138	38o Perse	3.9	36 48	3.74	31 54 25.2	11.73	+ .03
336	1140	14 Tauri	6.0	36 51	3.46	19 17 03.8	11.73	− .05
337	1139	ν Persei	4.0	37 03	4.05	42 11 52.3	11.71	− .03
338	1137	Camelopardalis	4.3	37 43	6.22	70 57 36.8	11.67	− .03
339	1147	17 Tauri	4.5	37 45	3.55	23 44 04.9	11.66	− .04
340	1151	q Tauri	4.9	38 04	3.56	24 05 22.2	11.64	− .06
341	1153	24 Eridani	5.4	3 38 25	+ 3.04	− 1 32 33.4	+ 11.62	− .01
342	1144	Camelopardalis	4.6	38 33	5.42	65 09 11.0	11.61	− .01
343	1154	20 Tauri	4.8	38 41	3.56	23 59 28.9	11.60	− .04
344	1161	23 Tauri	4.6	39 12	3.55	23 34 23.9	11.56	− .03
345	1162	u Tauri	5.4	39 18	3.18	5 40 22.6	11.56	− .04
346*	. .	Persei	6.0	39 28	4.39	50 21 46.0	11.54	...
347	1166	η Tauri	2.8	40 21	3.55	23 43 58.0	11.48	− .06
348	1174	e Tauri	5.0	41 41	3.28	10 46 21.1	11.38	− .05
349	1172	Persei	6.0	41 43	4.16	44 35 59.7	11.38	.00
350	1175	n Persei	5.5	41 58	3.78	32 43 19.5	11.36	− .01

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B.A.C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
351	1176	27 Tauri	4.2	3 42 02	+ 3.55	23 41 05.8	+ 11.36	− .07
352	1192	Tauri	5.8	43 06	3.60	25 12 54.1	11.28	− .25
353*	. .	Camelopardalis	6.0	44 ..	4.82	57 36	11.21	...
354	1207	ζ Persei	2.9	46 35	3.78	31 31 33.4	11.02	− .02
355	1203	Camelopardalis	5.4	46 51	5.22	62 43 07.4	11.01	+ .05
356	1204	Camelopardalis	5.7	46 55	5.07	60 45 21.2	11.00	+ .06
357	1210	Persei	5.7	47 20	4.29	47 31 02.1	10.97	.00
358	1214	A Persei	5.6	47 41	4.43	50 20 45.5	10.94	− .16
359	1221	32 Tauri	5.8	49 47	3.54	22 07 50.4	10.79	− .14
360	1219	ε Persei	3.1	49 48	4.00	39 39 41.5	10.79	− .03
361	1211	Cephei	4.9	3 50 01	+ 9.72	80 21 53.9	+ 10.77	+ .05
362	1228	ξ Persei	4.1	51 11	3.88	35 26 40.3	10.69	− .04
363	1240	Tauri	5.8	53 54	3.44	17 51 14.9	10.49	− .03
364*	. .	Camelopardalis	5.8	54.0	5.94	68 20	10.48	...
365	1241	λ Tauri	var. 3.5–4.0	54 02	3.32	12 09 00.3	10.48	− .02
366	1237	Camelopardalis	5.1	54 28	4.95	58 49 11.8	10.44	− .01
367*	1244	Tauri	5.7	55 13	3.27	9 39 35.0	10.39	...
368	1245	35 Eridani	5.4	55 27	3.03	− 1 53 15.1	10.37	− .05
369	1251	ν Tauri	4.1	56 46	3.19	5 39 18.7	10.27	− .01
370	1253	36 Tauri	5.9	57 11	3.58	23 46 27.5	10.24	+ .01
371	. .	D. M. 53°, 732	5.8	3 57 16	+ 4.63	53 41 01.4	+ 10.23	...
372	. .	• Tauri	5.7	57 26	3.22	7 51 50.7	10.22	...
373	1257	A Tauri	4.8	57 37	3.53	21 45 08.6	10.20	− .09
374	1254	λ Persei	4.7	57 38	4.44	50 01 25.0	10.20	− .06
375*	. .	Tauri	5.7	57.9	3.12	2 30	10.19	...
376	1262	41 Tauri	5.1	59 15	3.67	27 16 31.0	10.08	− .02
377	1265	ψ Tauri	5.3	59 36	3.70	28 40 31.9	10.06	+ .02
378*	. .	D. M. 54, 740	5.8	59.9	4.70	54 30	10.04	...
379	1266	c Persei	4.5	49 57	4.33	47 23 24.9	10.03	− .05
380	1268	49 Persei	5.7	4 00 20	3.95	37 24 40.2	10.00	− .14
381	1247	Cephei	5.1	4 00 32	+13.26	83 30 36.0	+ 9.98	...
382	1269	50 Persei	5.5	00 37	3.99	37 43 26.8	9.98	− .20
383	1272	Tauri	5.6	01 07	3.43	17 01 04.2	9.94	− .01
384	1279	p Tauri	5.7	03 32	3.64	26 09 59.3	9.76	.00
385*	1263	Cephei	5.1	03 46	12.65	83 03	9.74	...
386	1285	45 Tauri	5.8	04 57	3.19	5 12 33.3	9.65	− .05
387*	. .	Tauri	6.0	05.6	3.43	16 58	9.60	...
388	1289	D. M. 22°, 649	5.8	05 44	3.55	22 06 13.0	9.59	+ .05
389	1287	μ Persei	4.4	06 05	4.37	48 06 08.1	9.56	− .06
390*	. .	Persei	6.0	06.1	3.98	37 39	9.56	...
391	1276	Cephei	5.6	4 06 14	+10.12	80 32 10.7	+ 9.55	...
392	1286	Camelopardalis	5.4	06 20	5.24	61 32 46.6	9.54	− .01
393	1291	f Persei	4.9	06 44	4.07	40 10 40.3	9.51	− .07
394	1296	6 Tauri	5.4	07 05	3.22	7 24 30.0	9.48	+ .01
395	. .	D. M. 12°, 564	5.8	07 09	3.33	12 26 49.9	9.48	...
396	1293	Camelopardalis	4.9	07 21	4.65	53 18 28.8	9.46	− .06
397	1298	47 Tauri	4.9	07 25	3.26	8 57 28.3	9.46	− .08
398	. .	Tauri	5.5	08 03	3.27	9 42 26.4	9.41	...
399	1304	μ Tauri	4.4	09 01	3.25	8 35 25.9	9.34	− .02
400	1301	b Persei	5.0	09 14	4.49	49 59 54.4	9.32	− .05

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
401	1300	Camelopardalis . . .	5.8	4 09 24	+ 5.58	64 50 41.2	+ 9.31	— .03
402	1307	D. M. 49°, 1155 . . .	5.8	10 13	4.47	49 45 17.7	9.25	...
403	1311	ω Tauri	5.3	10 14	3.51	20 16 53.6	9.25	— .06
404	1316	51 Tauri	5.8	11 17	3.54	21 17 04.9	9.24	— .05
405	1313	Camelopardalis . . .	5.5	11 23	5.18	60 26 53.6	9.23	— .07
406	1324	56 Tauri	5.7	12 30	3.55	21 28 58.0	9.06	— .01
407	1322	54 Persei	5.2	12 37	3.88	34 16 31.1	9.06	— .04
408	1323	d Persei	5.3	12 52	4.32	46 12 36.9	9.03	— .05
409	1328	γ Tauri	4.0	12 58	3.41	15 20 11.6	9.03	— .00
410	1326	φ Tauri	5.3	12 58	3.67	27 03 44.2	9.03	— .07
411	1330	h Tauri	5.6	4 13 12	+ 3.38	13 44 38.8	+ 9.01	— .01
412	. .	Tauri	6.0	13 27	3.47	18 27 14.8	8.99	...
413	1332	58 Tauri	5.8	13 48	3.40	14 48 21.6	8.96	— .05
414†	1341	χ Tauri	5.5	15 17	3.64	25 20 40.3	8.85	— .01
415	1343	60 Tauri	5.6	15 18	3.37	13 47 31.0	8.85	— .01
416	1346	δ Tauri	4.1	16 01	3.46	17 15 35.0	8.79	— .03
417	1350	63 Tauri	5.9	16 32	3.44	16 29 44.7	8.75	+ .01
418	1349	55 Persei	5.8	16 42	3.88	33 51 03.4	8.73	— .05
419	1352	56 Persei	5.9	16 51	3.88	33 40 53.7	8.72	— .08
420	1356	64 Tauri	5.1	17 11	3.45	17 09 53.5	8.70	.00
421	1357	r Tauri	5.1	4 17 19	+ 3.27	9 10 48.3	+ 8.69	— .05
422	1362	κ Tauri	4.5	18 13	3.57	22 01 04.0	8.62	— .05
423	1363	67 Tauri	5.9	18 16	3.57	21 55 26.1	8.61	— .02
424	1364	Persei	5.2	18 28	3.81	31 09 59.7	8.59	— .12
425	1365	68 Tauri	4.8	18 33	3.46	17 39 07.7	8.59	+ .01
426	1367	υ Tauri	4.6	19 08	3.58	22 32 23.6	8.54	— .05
427	1369	71 Tauri	5.3	19 31	3.41	15 20 38.2	8.51	— .04
428	. .	Camelopardalis . . .	5.8	19 37	6.85	72 16 03.0	8.51	...
429	1370	π Tauri	4.9	19 50	3.38	14 26 27.7	8.49	— .03
430*	. .	Tauri	6.0	21.3	3.78	30 07	8.37	...
431	1377	75 Tauri	5.5††	4 21 35	+ 3.42	16 05 24.5	+ 8.35	+ .04
432	1376	ε Tauri	3.8	21 37	3.50	18 54 47.4	8.35	— .01
433	1380	ϑ Tauri	4.0	21 43	3.41	15 41 40.5	8.34	— .02
434	1381	ϑ^2 Tauri	4.0	21 48	3.42	15 36 12.5	8.33	— .02
435	1384	b Tauri	5.0	22 07	3.36	12 46 49.6	8.31	— .01
436	1386	44 Eridani	5.6	22 20	3.10	1 06 47.8	8.29	+ .01
437	1382	1 Camelopardalis . . .	5.8	22 32	4.73	53 38 52.0	8.28	— .01
438	1390	80 Tauri	6.3	23 18	3.41	15 22 26.0	8.21	— .03
439	1391	Tauri	4.9	23 42	3.43	15 55 54.0	8.18	— .01
440	1392	81 Tauri	6.0	23 48	3.42	15 25 45.6	8.17	— .01
441	1393	83 Tauri	5.6	4 23 52	+ 3.37	13 27 43.1	+ 8.17	— .02
442	1403	45 Eridani	5.1	25 44	3.06	— 0 18 11.0	8.02	— .07
443	1409	ρ Tauri	5.1	27 02	3.40	14 35 26.2	7.92	— .03
444	1408	Tauri	5.6	27 08	3.75	28 42 29.6	7.91	— .09
445*	. .	Tauri	5.8	27.8	3.19	5 19	7.85	...
446	1414	e Persei	4.4	28 23	4.14	41 01 00.3	7.80	— .01
447	1420	α Tauri	1.1	29 02	3.44	16 16 00.3	7.75	— .17
448	1421	d Tauri	4.4	29 04	3.29	9 54 46.3	7.75	— .05
449	1424	2 Camelopardalis . . .	5.5	30 28	4.73	53 14 04.8	7.63	— .09
450	1425	3 Camelopardalis . . .	5.5	30 28	4.70	52 50 18.1	7.63	— .03

† Double. †† Suspected variable, ♅ 5.3, D. M. 4.9, ♄ 6.3.

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
451	1431	49 Eridani	5.4	4 31 03	+ 3.09	0 45 13.5	+ 7.59	− .02
452*	. .	Tauri	5.8	31.2	3.53	20 27	7.58	...
453	1434	c Tauri	4.2	31 27	3.35	12 16 07.2	7.56	− .01
454	1436	σ Tauri (pr.)	5.4	32 18	3.42	15 33 43.5	7.49	− .08
455	1437	σ Tauri (sq.)	5.4	32 25	3.43	15 40 44.0	7.48	− .01
456	. .	Persei	5.9	32 27	4.45	48 03 57.6	7.47	...
457*	. .	Tauri	5.7	32 36	3.24	7 37 53.2	7.46	...
458	1428	Camelopardalis	6.0	32 45	7.98	75 43 10.2	7.45	− .10
459	1442	93 Tauri	5.5	33 23	3.34	11 57 38.3	7.40	+ .03
460	1444	Tauri	5.2	33 49	3.75	28 22 51.8	7.37	− .04
461*	. .	Persei	6.1	4 34 15	+ 4.54	49 44 32.8	+ 7.33	...
462	1445	59 Persei	5.6	34 24	4.24	43 08 05.3	7.32	− .07
463	1449	τ Tauri	4.6	35 03	3.59	22 43 31.1	7.27	− .02
464	1460	Orionis	5.6	37 47	3.33	10 55 16.8	7.06	.00
465	1448	Cephei	5.2	37 57	10.97	80 59 22.2	7.02	.00
466	1456	4 Camelopardalis	5.4	38 01	4.97	56 32 29.8	7.02	− .17
467*	. .	Orionis	5.6	39.4	3.33	11 29	6.91	...
468	1470	Camelopardalis	5.7	40 51	5.57	63 17 54.3	6.79	− .07
469	1475	Aurigæ	5.8	41 33	3.87	32 22 34.2	6.72	.00
470*	. .	Aurigæ	5.5	41.5	3.83	31 13	6.73	...
471	1476	1 Aurigæ	5.4	4 41 50	+ 4.03	37 16 30.4	+ 6.72	+ .06
472	1474	9 Camelopardalis	4.7	42 08	5.91	66 08 10.8	6.69	+ .01
473	1477	Aurigæ	5.9	42 08	4.50	48 31 53.4	6.69	.00
474	1486	π^1 Orionis	3.5	43 20	3.26	6 45 00.5	6.58	− .01
475	1491	π^2 Orionis	4.8	44 05	3.27	8 41 34.0	6.52	− .04
476	1493	i Tauri	4.9	44 21	3.50	18 38 02.4	6.50	− .07
477	1492	2 Aurigæ	5.0	44 36	4.01	36 29 56.0	6.48	+ .01
478	1495	π^3 Orionis	4.0	44 49	3.19	5 23 53.4	6.46	− .03
479	1494	5 Camelopardalis	5.7	45 15	4.88	55 03 29.2	6.42	− .09
480	1497	D. M. 27°, 701	5.8	45 18	3.75	27 41 42.3	6.42	− .06
481	1500	40^1 Orionis	5.2	4 45 45	+ 3.39	14 02 56.9	+ 6.38	− .08
482	1508	5 Orionis	5.5	47 07	3.13	2 18 31.4	6.27	− .03
483	1504	7 Camelopardalis	4.9	47 40	4.79	53 33 27.7	6.22	.00
484	1514	π^5 Orionis	3.9	48 00	3.12	2 14 33.5	6.20	.00
485	1516	π^4 Orionis	5.1	48 18	3.30	9 57 30.1	6.17	− .18
486	. .	Orionis	5.6	48 19	3.24	7 35 01.6	6.17	...
487	1520	ι Aurigæ	3.1	49 11	3.90	32 58 28.1	6.10	− .02
488	. .	Cephei	6.0	49 26	20.42	85 47 53.8	6.08	...
489	1525	90^2 Orionis	4.8	49 37	3.37	13 19 24.2	6.06	− .05
490	1526	Tauri	5.3	50 27	3.47	16 57 51.7	6.00	− .01
491	1528	k Tauri	5.8	4 50 49	+ 3.66	24 51 48.7	+ 5.97	− .06
492	1530	4 Aurigæ	5.7	51 07	4.07	37 42 24.7	5.94	− .09
493	1538	π^6 Orionis	4.7	52 20	3.11	1 31 43.1	5.83	+ .01
494	1536	10 Camelopardalis	4.3	52 45	5.31	60 15 51.0	5.80	− .02
495	1540	ε Aurigæ	var. 3.5–4.1	53 21	4.29	43 38 38.3	5.75	.00
496	1541	ζ Aurigæ	3.8	54 05	4.18	40 53 56.9	5.69	.00
497	1546	11 Camelopardalis	5.4	55 43	5.20	58 48 08.8	5.55	− .01
498	1551	ι Tauri	4.8	55 55	3.58	21 25 01.5	5.53	− .06
499	1549	Camelopardalis	5.4	57 14	7.48	73 47 17.9	5.43	− .03
500	1554	9 Aurigæ	5.4	57 17	4.68	51 26 11.2	5.42	− .15

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
501	1557	11 Orionis	4.9	4 57 43	+ 3.42	15 14 07.5	+ 5.39	— .01
502	1558	η Aurigæ	3.4	58 06	4.19	41 04 13.0	5.35	— .09
503*	. .	D. M. + 0°, 339	5.8	59.2	3.10	1 01	5.26	...
504	1568	m Tauri	5.1	5 00 22	3.54	18 28 56.8	5.16	+ .02
505	1570	l Tauri	5.4	00 42	3.55	20 15 30.4	5.13	— .04
506	1572	103 Tauri	5.7	00 48	3.65	24 06 19.7	5.12	+ .05
507	1584	i Orionis	5.8	01 21	3.26	8 20 25.9	5.08	— .06
508	1582	Aurigæ	5.7	01 47	4.46	46 48 43.7	5.04	— .10
509*	. .	Tauri	5.6	02.2	3.75	27 53	5.00	...
510	1590	h Orionis	5.9	02 44	3.29	9 40 24.7	4.96	— .11
511	1565	Camelopardalis	5.0	5 02 48	+ 9.74	79 05 18.4	+ 4.95	+ .05
512	1591	15 Orionis	5.0	02 50	3.43	15 26 33.7	4.95	+ .02
513*	1585	Camelopardalis	5.7	03 26	7.35	73 07 37.6	4.88	...
514	1601	Orionis	5.6	04 48	3.45	15 53 42.9	4.78	— .10
515	1602	μ Aurigæ	5.2	05 13	4.10	38 20 26.5	4.75	— .06
516	1611	ρ Orionis	4.9	07 01	3.14	2 43 00.7	4.60	— .01
517	1614	14 Aurigæ	5.4	07 36	3.90	32 32 49.0	4.54	+ .02
518	1613	α Aurigæ	0.3	07 50	4.42	45 52 26.1	4.53	— .43
519	. .	Orionis	5.8	08.4	3.19	5 01	4.48	...
520	. .	Camelopardalis	5.8	09.2	5.58	62 31	4.41	...
521	1624	18 Orionis	5.9	5 09 24	+ 3.33	11 18 17.9	+ 4.39	+ .02
522	. .	Aurigæ	6.0	09 42	4.27	42 39 36.0	4.37	.00
523	1627	16 Aurigæ	5.1	10 18	3.93	33 14 41.1	4.31	— .15
524	1631	λ Aurigæ	4.9	10 42	4.20	39 59 24.5	4.28	— .70
525*	. .	Aurigæ	5.8	11.8	4.21	40 58	4.19	...
526	1637	n Tauri	5.5	12 04	3.60	21 58 16.5	4.16	+ .03
527	1636	19 Aurigæ	5.6	12 06	3.95	33 49 50.1	4.16	— .01
528	1642	16 Camelopardalis	5.3	13 11	5.12	57 25 30.5	4.05	— .05
529	1645	ρ Aurigæ	5.6	13 19	4.25	41 40 58.8	4.06	— .03
530	1649	D. M. 29°, 869	5.8	13 35	3.81	29 26 41.5	4.03	— .12
531	. .	Aurigæ	5.9	5 14 25	+ 4.21	40 54 33.8	+ 3.96	.00
532	1660	22 Orionis	4.9	15 38	3.06	— 0 30 09.3	3.86	— .02
533	1663	σ Aurigæ	5.5	16 30	4.07	37 16 17.8	3.78	.00
534	1665	m Orionis	5.3	16 32	3.15	3 25 38.8	3.78	— .01
535	1671	111 Tauri	5.4	17 25	3.50	17 16 13.9	3.71	.00
536	1682	p Orionis	5.7	18 23	3.05	— 1 00 29.4	3.62	+ .10
537	1685	25 Orionis	5.0	18 31	3.12	1 44 04.4	3.61	.00
538	1687	γ Orionis	1.5	18 42	3.22	6 14 21.9	3.59	— .04
539	1681	β Tauri	1.6	18 42	3.79	28 30 15.5	3.59	— .17
540	1676	17 Camelopardalis	5.8	18 50	5.65	62 57 51.1	3.58	— .01
541	1690	φ Aurigæ	5.6	5 19 42	+ 3.98	34 22 17.8	+ 3.51	— .05
542	1692	115 Tauri	5.8	20 10	3.49	17 51 26.5	3.47	— .02
543	1695	o Tauri	5.6	20 26	3.60	21 49 58.6	3.45	— .01
544	1700	ψ Orionis	5.1	20 33	3.14	2 59 24.8	3.44	— .01
545	1701	116 Tauri	5.8	20 52	3.45	15 46 16.4	3.40	— .02
546	1707	118 Tauri	5.5	21 53	3.69	25 03 05.0	3.32	— .05
547	1717	31 Orionis	5.3	23 38	3.05	— 1 11 17.6	3.17	.00
548	1662	Cephei	6.0	23 41	18.58	85 07 53.3	3.16	...
549	1722	A Orionis	5.2	24 22	3.21	5 51 19.3	3.11	— .02
550	1723	χ Aurigæ	4.9	24 55	3.91	32 06 07.2	3.06	+ .04

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
551	1726	119 Tauri	4.7	5 25 11	+ 3.52	18 30 11.7	+ 3.03	− .01
552	1730	δ Orionis	var. 2.2–2.8	25 53	3.06	− 0 23 22.8	2.97	− .01
553	. .	Aurigæ	5.8	26 44	4.91	54 20 47.2	2.90	.00
554*	. .	Orionis	5.8	26.7	3.03	− 1 41	2.90	...
555	1737	35 Orionis	5.6	27 05	3.41	14 13 09.8	2.87	− .03
556	1736	Aurigæ	5.8	27 12	4.52	47 38 02.5	2.86	.00
557	1742	121 Tauri	5.6	28 08	3.66	23 57 28.5	2.78	− .02
558	1748	φ¹ Orionis	4.9	28 14	3.29	9 24 24.0	2.77	− .02
559	1749	λ Orionis	3.8	28 32	3.30	9 51 08.0	2.75	− .02
560	1765	ε Orionis	1.8	30 07	3.04	− 1 16 48.3	2.61	− .01
561	1766	φ² Orionis	4.5	5 30 19	+ 3.30	9 13 26.3	+ 2.59	− .31
562	1751	Camelopardalis	5.8	30 25	6.00	65 37 47.7	2.58	...
563	1767	ζ Tauri	2.9	30 28	3.58	21 04 03.1	2.57	− .05
564*	. .	D. M. 4°, 989	5.8	30.8	3.18	4 41	2.55	...
565	1768	26 Aurigæ	5.8	30 56	3.85	30 25 09.5	2.54	.00
566	1778	125 Tauri	5.7	32 18	3.72	25 49 41.8	2.42	− .01
567	1782	ω Orionis	4.9	32 51	3.17	4 03 06.6	2.37	+ .01
568	1792	126 Tauri	5.4	34 22	3.46	16 28 13.6	2.24	+ .02
569	1806	b Orionis	5.4	36 16	3.10	1 24 54.3	2.07	− .01
570	1804	ο Aurigæ	5.8	36 36	4.65	49 46 16.2	2.04	− .08
571*	1826	Orionis	5.8	5 40.3	+ 3.30	9 29	+ 1.72	...
572	1827	131 Tauri	5.7	40 23	3.42	14 26 32.2	1.71	− .09
573	1830	τ Aurigæ	4.7	40 52	4.16	39 08 16.0	1.67	− .06
574	1834	133 Tauri	5.2	40 55	3.41	13 51 16.0	1.67	− .01
575	1839	52 Orionis	5.5	41 33	3.23	6 24 37.2	1.61	− .06
576	1837	132 Tauri	5.3	41 39	3.68	24 31 32.2	1.61	− .01
577	1846	134 Tauri	5.1	42 49	3.37	12 36 42.7	1.50	+ .02
578	1844	υ Aurigæ	5.0	42 51	4.09	37 16 08.9	1.49	− .03
579	1845	ν Aurigæ	4.2	43 10	4.16	39 06 42.3	1.47	+ .03
580	1851	Orionis	5.8	43 26	3.31	9 49 53.5	1.45	− .19
581	1852	135 Tauri	5.6	5 43 39	+ 3.41	14 16 08.3	+ 1.43	− .02
582*	. .	Orionis	5.8	43.9	3.17	4 23	1.41	...
583	1849	31 Camelopardalis	5.4	44 13	5.37	59 51 30.9	1.38	− .02
584	1854	ξ Aurigæ	4.9	44 47	5.02	55 40 34.0	1.33	− .03
585*	. .	D. M. 19°, 1110	5.8	45.3	3.55	19 50	1.29	...
586	1862	137 Tauri	5.8	45 34	3.41	14 08 23.0	1.26	− .02
587	1863	136 Tauri	5.3	45 47	3.77	27 34 54.7	1.24	− .07
588	1869	56 Orionis	5.4	46 13	3.12	1 49 27.0	1.21	+ .01
589	1876	χ¹ Orionis	4.8	47 17	3.55	20 15 07.7	1.11	− .10
590	1883	α Orionis	var. 0.4–1.4	48 41	3.24	7 22 59.7	0.98	+ .02
591	. .	D. M. 24°, 1033	5.8	5 49 35	+ 3.67	24 13 48.2	+ 0.91	...
592	1885	δ¹ Aurigæ	3.9	49 39	4.94	54 16 23.2	0.91	− .11
593	. .	Aurigæ	6.0	50 02	4.66	49 54 33.8	0.87	...
594	1896	139 Tauri	5.2	50 33	3.73	25 56 14.0	0.83	.00
595	1895	β Aurigæ	2.0	50 44	4.40	44 55 58.8	0.81	− .03
596	1897	π Aurigæ	4.6	51 02	4.45	45 55 25.6	0.79	− .02
597	1900	ϑ Aurigæ	2.5	51 32	4.09	37 12 08.4	0.74	− .11
598	1902	36 Aurigæ	5.9	51 52	4.55	47 53 30.3	0.71	− .05
599	1913	60 Orionis	5.5	52 39	3.09	0 32 25.1	0.65	− .04
600	1914	Aurigæ	6.2	53 29	4.66	49 54 11.0	0.57	+ .10

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
601	1928	μ Orionis	4.8	5 55 47	+ 3.30	9 38 44.7	+ 0.37	— .01
602	1934	64 Orionis	5.7	56 21	3.56	19 41 27.5	0.32	— .03
603	1939	χ^2 Orionis	5.1	56 47	3.56	20 08 21.3	0.28	— .04
604	1938	1 Geminorum	4.9	56 50	3.64	23 16 05.6	0.28	— .11
605	1942	40 Aurigæ	5.7	58 19	4.13	38 29 30.3	0.15	.00
606*	. .	D. M. 29°, 1112 . . .	5.8	58.7	3.83	29 31	0.11	...
607	1945	66 Orionis	5.8	58 38	3.17	4 09 50.8	0.12	— .03
608	1943	37 Camelopardalis . . .	5.8	59 24	5.30	58 56 54.6	0.05	+ .01
609	1958	ν Orionis	4.6	6 00 43	3.43	14 46 52.5	— 0.06	— .02
610	1952	36 Camelopardalis . . .	5.6	00 46	6.03	65 44 21.2	0.06	— .02
611	1963	41 Aurigæ	6.2	6 02 25	+ 4.60	48 43 58.0	— 0.21	— .12
612	. .	Aurigæ	6.0	04 17	4.73	51 12 06.2	0.38	...
613	. .	Aurigæ	6.0	04.5	3.93	32 43	0.39	...
614	1979	40 Camelopardalis . . .	5.7	04 54	5.39	60 01 46.4	0.43	— .03
615	1986	68 Orionis	5.8	04 55	3.56	19 48 54.2	0.43	— .06
616	1990	ξ Orionis	4.7	05 07	3.42	14 14 03.4	0.45	— .04
617	1989	f¹ Orionis	5.7	05 08	3.46	16 09 22.2	0.45	+ .02
618	1980	Camelopardalis . . .	4.6	05 37	6.62	69 21 32.7	0.49	— .11
619	1992	1 Lyncis	5.6	06 51	5.54	61 33 05.2	0.60	— .01
620	2002	η Geminorum	3.6	07 38	3.62	22 32 24.0	0.67	— .02
621	2001	κ Aurigæ	4.4	6 07 44	+ 3.83	29 32 25.3	— 0.68	— .29
622	2009	f² Orionis	5.5	08 30	3.45	16 10 42.7	0.74	+ .05
623	2012	73 Orionis	5.8	09 01	3.38	12 35 13.4	0.79	.00
624	2007	2 Lyncis	4.8	09 02	5.30	59 03 06.5	0.79	+ .03
625*	. .	D. M. 14°, 1235 . . .	5.8	11.3	3.42	14 26	0.99	...
626	2024	45 Aurigæ	5.6	12 01	4.88	53 30 15.3	1.05	— .10
627*	. .	Orionis	5.7	13.2	3.42	14 43	1.15	...
628	. .	Camelopardalis . . .	5.8	14 33	6.86	70 35 49.7	1.26	...
629	2044	ψ^1 Aurigæ	4.9	15 39	4.62	49 20 47.1	1.37	— .06
630	2047	μ Geminorum	3.3	15 42	3.63	22 34 25.0	1.38	— .11
631*	2045	5 Lyncis	5.8	6 16 20	+ 5.25	58 28 49.7	— 1.40	— .03
632	2059	8 Monocerotis . . .	4.7	17 25	3.18	4 39 08.0	1.52	— .02
633	2082	48 Aurigæ	5.5	20 51	3.86	30 33 53.8	1.82	— .04
634	2086	77 Orionis	5.7	21 04	3.08	0 22 11.2	1.84	— .05
635	2081	47 Aurigæ	6.1	21 05	5.49	46 45 33.2	1.84	— .03
636*	2069	Camelopardalis . . .	5.6	21 49	9.38	78 05 11.0	1.93	...
637	2090	ν Geminorum	4.4	21 50	3.56	20 17 10.9	1.90	— .01
638	2083	Camelopardalis . . .	6.0	22 46	7.65	73 47 06.3	1.99	...
639	2110	Aurigæ	5.7	24 37	3.93	32 32 21.4	2.15	+ .02
640*	. .	Monocerotis . . .	5.2	25.1	3.35	11 38	2.19	...
641	2095	Camelopardalis . . .	5.3	6 25 45	+10.35	79 41 22.7	— 2.24	— .61
642	2126	13 Monocerotis . . .	4.8	26 25	3.25	7 25 10.3	2.30	— .02
643*	. .	Camelopardalis . . .	5.8	26.4	7.12	71 51	2.30	...
644*	2129	Geminorum	6.0	26.8	3.41	14 15	2.34	...
645*	. .	Monocerotis . . .	5.5	27.5	3.05	— 1 07	2.40	...
646	2133	4) Aurig	5.1	27 39	3.78	28 06 50.3	2.41	— .02
647	2159	ψ^2 Aurigæ	5.0	30 46	4.29	42 35 32.1	2.69	— .05
648	2163	γ Geminorum	1.9	30 47	3.47	16 30 00.5	2.69	— .03
649	2170	54 Aurigæ	5.9	31 59	3.79	28 22 01.8	2.79	— .04
650	2182	ψ Aurigæ	5.1	34 21	4.37	44 38 16.1	2.99	+ .06

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	+ Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
651	2185	S Monocerotis	var. 4.7–5.5	6 34 22	+ 3.31	10 00 16.1	− 3.00	− .09
652	2191	26 Geminorum	5.5	35 25	3.49	17 45 41.4	3.09	− .08
653	2187	12 Lyncis	4.9	35 37	5.30	59 33 37.1	3.10	− .03
654	2194	ε Geminorum	3.3	36 33	3.69	25 14 54.1	3.18	− .02
655	2197	28 Geminorum	5.8	37 09	3.81	29 05 25.9	3.23	− .03
656	2199	30 Geminorum	4.9	37 13	3.38	13 20 51.3	3.24	− .02
657	2200	ψ^5 Aurigæ	5.3	38 05	4.33	43 41 40.9	3.32	+ .14
658	. .	Lyncis	5.8	38 12	5.01	55 50 02.5	3.33	. . .
659	2198	42 Camelopardalis . . .	5.0	38 26	6.29	67 42 04.6	3.34	+ .01
660	2201	ψ^6 Aurigæ	5.4	38 31	4.59	48 54 50.1	3.35	− .04
661	2206	ξ Geminorum	3.8	6 38 33	+ 3.37	13 01 24.2	− 3.36	− .22
662	2211	16 Monocerotis	5.8	40 00	3.27	8 42 45.2	3.48	− .02
663	2209	43 Camelopardalis . . .	5.1	40 45	6.51	69 01 28.6	3.55	.00
664	2216	17 Monocerotis	5.1	40 49	3.27	8 09 57.0	3.55	.00
665	2222	18 Monocerotis	4.8	41 36	3.13	2 32 30.8	3.62	− .03
666*	. .	Geminorum	5.7	41.9	3.92	32 44	3.65	. . .
667	2223	ψ^7 Aurigæ	5.1	42 17	4.25	41 55 15.1	3.68	− .11
668	2220	14 Lyncis	5.8	42 30	5.31	59 35 18.3	3.70	− .04
669	2210	Camelopardalis . . .	4.6	42 32	8.85	77 07 33.9	3.70	− .03
670	2157	Cephei	5.0	43 45	30.12	87 13 45.6	3.81	− .05
671	2233	d Geminorum	5.8	6 44 22	+ 3.61	21 54 04.2	− 3.86	− .02
672	2237	ϑ Geminorum	3.6	44 52	3.96	34 06 15.1	3.89	− .05
673	2248	15 Lyncis	4.9	46 53	5.22	58 34 38.3	4.07	− .18
674	2247	Camelopardalis . . .	6.0	47 42	6.86	70 57 58.5	4.14	. . .
675	2255	c Geminorum	5.0	47 52	3.38	13 19 43.9	4.16	− .06
676	2261	ψ^{10} Aurigæ	5.2	48 52	4.39	45 14 51.8	4.24	− .02
677	2285	41 Geminorum	5.8	53 22	3.45	16 14 38.3	4.62	+ .04
678	2299	ω Geminorum	5.6	55 06	3.66	24 23 05.2	4.77	− .01
679*	. .	Geminorum	6.0	55.4	3.49	17 55	4.80	. . .
680*	. .	Geminorum	6.0	55.4	3.43	15 30	4.80	. . .
681	2305	ζ Geminorum	var. 3.8–4.4	6 56 59	+ 3.56	20 44 40.8	− 4.94	− .01
682	2306	Geminorum	5.1	56 59	3.33	11 07 35.5	4.94	.00
683	2314	Aurigæ	6.0	58 16	3.98	34 39 14.7	5.05	− .17
684*	. .	Aurigæ	5.8	59.5	3.95	34 11	5.14	. . .
685*	. .	Monocerotis	5.7	7 01.3	3.25	7 40	5.30	. . .
686	2330	45 Geminorum	5.4	01 29	3.44	16 07 15.6	5.32	− .07
687	2338	63 Aurigæ	5.1	03 24	4.13	39 30 52.3	5.47	.00
688	2340	τ Geminorum	4.6	03 30	3.83	30 26 24.3	5.50	− .06
689	2343	47 Geminorum	5.7	03 56	3.72	27 03 08.3	5.52	− .03
690	2341	D. M. 51°, 1295 . . .	5.8	04 02	4.70	51 37 31.7	5.53	.00
691	2350	48 Geminorum	5.8	7 05 09	+ 3.65	24 19 40.9	− 5.62	− .01
692	2349	18 Lyncis	5.1	05 25	5.27	59 50 54.1	5.64	− .33
693	2356	Canis Minoris . . .	5.8	05 27	3.21	5 51 07.4	5.64	.00
694	2358	22 Monocerotis	4.4	05 44	3.07	− 0 17 43.0	5.67	− .01
695	2326	Camelopardalis . . .	5.3	05 45	12.99	82 38 14.6	5.67	− .02
696	2362	51 Geminorum	5.3	06 29	3.44	16 21 40.2	5.74	− .03
697	2361	Lyncis	5.7	06 55	4.47	47 27 06.2	5.77	− .02
698	2373	Monocerotis	5.6	08 02	3.15	3 18 57.0	5.87	+ .01
699	2379	Lyncis	5.2	09 25	4.57	49 40 35.1	5.98	.00
700	2381	64 Aurigæ	6.0	09 42	4.18	41 05 40.9	6.01	+ .01

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
701	2398	λ Geminorum	4.0	7 11 12	+ 3.45	16 45 19.9	− 6.13	− .04
702	. .	Lyncis	6.0	12 36	4.36	45 26 53.5	6.25	. . .
703	2410	δ Geminorum	3.5	12 57	3.59	22 12 06.5	6.28	+ .01
704	2407	19 Lyncis	5.4	13 04	4.92	55 30 19.2	6.27	− .05
705	2416	65 Aurigæ	5.3	14 02	4.03	36 59 05.5	6.36	.00
706	2423	56 Geminorum	5.6	14 52	3.55	20 40 06.9	6.44	.00
707	2429	66 Aurigæ	5.4	15 50	4.17	40 54 07.1	6.51	− .01
708	2431	A Geminorum	5.1	16 10	3.67	25 16 46.6	6.54	− .02
709	2441	21 Lyncis	4.8	17 40	4.55	49 26 50.7	6.67	− .09
710	2442	ι Geminorum	4.0	18 16	3.74	28 02 06.2	6.72	− .09
711	2444	1 Canis Minoris . . .	5.7	7 18 18	+ 3.34	11 54 13.6	− 6.72	+ .02
712	2439	Camelopardalis . . .	5.6	18 23	6.29	68 42 28.3	6.73	− .07
713	2451	ε Canis Minoris . . .	5.3	19 05	3.28	9 30 39.8	6.79	− .07
714	. .	Lyncis	5.9	19 55	4.36	48 25 35.3	6.85	. . .
715	2460	63 Geminorum	5.5	20 37	3.57	21 41 20.6	6.90	− .10
716	2462	β Canis Minoris . . .	2.8	20 39	3.26	8 31 47.4	6.91	− .05
717	2459	22 Lyncis	5.5	20 49	4.56	49 55 04.8	6.93	− .11
718	2464	ρ Geminorum	4.5	21 23	3.87	32 01 17.3	6.97	+ .19
719	2465	η Canis Minoris . . .	5.8	21 35	3.23	7 11 06.8	6.99	− .04
720	2468	γ Canis Minoris . . .	4.9	21 38	3.27	9 10 01.5	6.97	− .02
721	2467	64 Geminorum	5.5	7 21 52	+ 3.75	28 21 50.5	− 7.01	− .04
722	2469	b Geminorum	5.0	22 21	3.74	28 09 43.7	7.05	− .01
723	2473	6 Canis Minoris . . .	4.9	23 07	3.34	12 15 12.4	7.11	.00
724*	. .	D. M. 23°, 1744 . . .	5.8	25.7	3.60	23 09	7.33	. . .
725	2480	δ^1 Canis Minoris . . .	5.4	25 52	3.12	2 10 04.2	7.34	+ .05
726	2486	68 Geminorum	5.4	26 46	3.43	16 05 00.5	7.41	.00
727	2485	α Geminorum	1.5	26 56	3.85	32 09 00.1	7.42	− .08
728	. .	Lyncis	6.0	27 01	4.91	56 01 03.2	7.43	. . .
729	2488	Lyncis	5.7	27 49	4.37	46 26 35.3	7.50	. . .
730	2493	ν Geminorum	4.3	28 32	3.71	27 09 39.9	7.55	− .11
731	2504	70 Geminorum	5.7	7 30 40	+ 3.95	35 18 55.3	− 7.73	− .03
732	2509	ο Geminorum	5.0	31 20	3.93	34 51 26.1	7.78	− .30
733	. .	Lyncis	6.0	32 10	4.05	38 37 02.9	7.85	.00
734	. .	Lyncis	5.8	32 20	4.46	48 24 40.0	7.86	.00
735	2519	f Geminorum	5.6	32 33	3.47	17 56 46.9	7.88	+ .01
736	2516	24 Lyncis	5.0	32 51	5.11	58 59 19.6	7.90	− .07
737	2522	α Canis Minoris . . .	0.5	33 01	3.14	5 31 51.7	7.92	−1.08
738*	. .	Geminorum	6.0	33.8	3.60	23 19	7.98	. . .
739	2532	Lyncis	5.3	34 59	4.57	50 42 57.2	8.08	− .04
740*	. .	Geminorum	6.0	35.3	3.39	14 29	8.10	. . .
741	2540	σ Geminorum	4.9	7 35 49	+ 3.76	29 10 20.4	− 8.14	− .24
742	2551	κ Geminorum	3.7	37·12	3.63	24 41 03.1	8.25	− .05
743	2555	β Geminorum	1.3	37 58	3.68	28 18 53.0	8.32	− .04
744*	. .	Lyncis	5.5	38.6	4.02	37 48	8.36	. . .
745	2558	81g Geminorum	5.1	39 11	3.48	18 48 05.1	8.41	− .05
746	2564	11 Canis Minoris . . .	5.2	39 40	3.31	11 03 35.0	8.45	+ .01
747	2563	π Geminorum	5.4	39 46	3.88	33 42 32.5	8.46	− .02
748	2612	ζ Canis Minoris . . .	5.3	45 29	3.12	2 04 19.4	8.91	− .01
749	2596	Camelopardalis . . .	5.1	45 48	7.31	74 14 08.0	8.93	. . .
750	2590	Camelopardalis . . .	5.4	45 51	9.70	79 48 12.2	8.93	−0.10

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
751	2609	26 Lyncis	5.6	7 45 58	+ 4.39	47 52 25.2	− 8.95	− .04
752	2617	φ Geminorum	5.1	46 09	3.68	27 04 29.9	8.96	− .01
753	2585	Camelopardalis	5.8	48 01	15.23	84 23 56.3	9.10	...
754	2632	85 Geminorum	8.9	48 40	3.51	20 11 58.2	9.16	− .04
755	2639	1 Cancri	6.1	50 11	3.41	16 06 34.3	9.28	− .04
756	2647	Canis Minoris	6.0	50 45	3.26	8 57 37.4	9.31	− .06
757	. .	Camelopardalis	5.8	51 16	5.07	59 22 15.1	9.36	...
758*	2649	Cancri	6.0	51 41	3.43	16 50	9.38	...
759	. .	Camelopardalis	5.8	51 45	5.43	63 25 03.8	9.40	.00
760	2653	14 Canis Minoris	5.8	52 07	3.12	2 32 33.9	9.42	+ .01
761	2659	3 Cancri	5.8	7 53 55	+ 3.44	17 38 09.4	− 9.56	− .04
762	2668	28 Monocerotis	5.1	55 07	3.06	− 1 03 38.4	9.65	− .10
763	2673	Canis Minoris	4.9	56 02	3.12	2 39 47.0	9.72	+ .12
764	2672	χ Geminorum	5.1	56 09	3.69	28 07 45.1	9.74	− .07
765	2690	8 Cancri	5.7	58 23	3.35	13 27 31.6	9.91	− .05
766	2700	9 Cancri	6.0	59 12	3.56	22 58 35.6	9.97	− .02
767	2697	27 Lyncis	4.9	59 25	4.54	51 51 03.0	9.98	− .01
768	2714	μ Cancri	5.3	8 00 42	3.54	21 55 43.8	10.08	− .07
769	2707	Ursæ Majoris	4.9	00 51	6.06	68 49 29.6	10.09	− .01
770	2732	Lyncis	5.6	04 16	4.82	56 48 37.5	10.35	+ .02
771	2722	Camelopardalis	5.5	8 04 25	+ 7.72	76 07 13.1	− 10.36	...
772	2744	ζ Cancri	4.7	05 20	3.45	18 00 30.7	10.43	− .11
773	2747	ψ Geminorum	5.5	05 43	3.73	30 00 51.0	10.45	− .06
774	2757	29 Lyncis	5.8	07 52	5.03	59 56 10.1	10.62	− .06
775	2765	Ursæ Majoris	6.0	08 50	5.28	62 52 32.8	10.69	.00
776	2778	β Cancri	3.9	10 00	3.26	9 33 14.7	10.77	− .05
777	2786	χ Cancri	5.5	12 46	3.66	27 36 18.0	10.98	− .38
778	2788	Cancri	5.8	13 23	3.52	21 07 31.7	11.02	+ .02
779	2789	λ Cancri	5.5	13 24	3.57	24 23 55.2	11.02	− .04
780	2793	31 Lyncis	4.4	14 37	4.13	43 34 18.4	11.11	− .10
781	2792	Lyncis	5.8	8 14 43	+ 4.58	53 36 17.8	− 11.12	− .04
782*	. .	Lyncis	5.8	17.4	3.86	35 24	11.31	...
783	2803	Ursæ Majoris	5.8	18 26	5.76	67 41 25.1	11.38	+ .04
784	2815	φ Cancri	5.9	19 10	3.66	28 17 14.9	11.44	− .10
785	. .	Lyncis	6.0	19 14	4.21	46 03 34.5	11.44	.00
786	2822	Cancri	5.2	19 29	3.22	7 57 15.7	11.47	− .04
787	2817	φ² Cancri	5.6	19 32	3.64	27 19 32.1	11.47	− .01
788	2826	27 Cancri	6.0	20 06	3.33	13 02 57.8	11.51	− .12
789	2819	o Ursæ Majoris	3.5	20 17	5.04	61 07 02.2	11.52	− .13
790	2833	28 Cancri	5.7	21 30	3.57	24 32 30.0	11.61	− .08
791	2842	A Ursæ Majoris	5.4	8 23 51	+ 5.45	65 33 07.6	− 11.77	− .08
792	2850	ι Cancri	5.7	24 25	3.56	24 29 04.1	11.82	− .07
793	2853	ϑ Cancri	5.6	24 45	3.43	18 29 55.9	11.84	− .06
794	2862	η Cancri	5.5	25 46	3.48	20 50 51.5	11.91	− .06
795	2871	33 Lyncis	6.0	27 01	3.87	36 49 48.7	12.00	− .01
796	2876	3 Ursæ Majoris	5.5	28 31	5.40	65 25 59.6	12.10	+ .05
797	2889	Hydræ	6.0	29 28	3.20	7 02 15.1	12.17	− .09
798	2884	π Ursæ Majoris	4.6	29 43	5.32	64 44 42.0	12.19	+ .02
799	2897	c Cancri	5.9	30 35	3.26	10 04 16.7	12.25	− .03
800	2901	δ Hydræ	4.4	31 18	3.18	6 07 17.0	12.30	+ .02

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
801	2911	σ Hydræ	4.8	8 32 29	+ 3.15	3 45 42.3	− 12.38	− .02
802	2909	34 Lyncis	5.4	32 43	4.17	46 15 12.3	12.40	+ .06
803	2937	γ Cancri	4.5	36 20	3.48	21 53 56.9	12.64	+ .01
804	2942	A^1 Cancri	5.8	36 35	3.31	13 06 36.1	12.66	+ .01
805	2945	η Hydræ	4.8	36 57	3.14	3 49 41.9	12.69	− .01
806	2953	δ Cancri	4.3	37 52	3.42	18 35 39.5	12.75	− .24
807*	2943	Ursæ Majoris . . .	6.0	37 56	5.52	67 08 50.0	12.75	+ .02
808	2958	b Cancri	5.6	38 14	3.26	10 30 54.0	12.77	− .03
809	2965	ι Cancri	4.1	39 26	3.64	29 11 50.7	12.85	− .05
810	2971	ϵ Hydræ	3.5	40 25	3.18	6 51 29.8	12.92	− .02
811	2976	Hydræ	5.5	8 41 10	+ 3.04	− 1 27 28.2	− 12.97	+ .03
812	2978	ρ Hydræ	4.8	42 05	3.19	6 16 48.0	13.02	− .03
813	2982	b Ursæ Majoris . . .	5.5	43 29	5.01	62 24 37.1	13.12	+ .17
814	2989	35 Lyncis	5.8	43 53	4.05	44 10 18.2	13.15	+ .03
815	2999	σ^1 Cancri	5.8	45 10	3.73	32 55 21.7	13.23	+ .02
816	3002	ρ Cancri	5.8	45 27	3.58	28 47 17.3	13.25	− .25
817	3003	6 Ursæ Majoris . . .	5.8	46 09	5.22	65 03 39.3	13.30	− .13
818	3016	57 Cancri	5.3	46 55	3.67	31 01 57.9	13.35	.00
819	3026	ρ^2 Cancri	5.4	48 28	3.60	28 23 03.6	13.45	− .04
820	3027	Ursæ Majoris . . .	6.0	48 43	3.92	40 39 38.6	13.46	.00
821	3032	ζ Hydræ	3.3	8 49 03	+ 3.18	6 24 04.4	− 13.48	.00
822	3035	60 Cancri	5.7	49 22	3.28	12 05 00.8	13.51	− .02
823	3033	σ^2 Cancri	5.6	49 32	3.72	33 22 14.7	13.51	− .07
824	. .	Camelopardalis . . .	5.8	50 03	13.61	84 39 31.0	13.55	.00
825	3047	υ Cancri	5.5	50 33	3.36	15 46 55.4	13.58	+ .04
826	3048	ι Ursæ Majoris . . .	3.2	50 59	4.14	48 30 40.6	13.61	− .28
827*	3053	Cancri	6.0	51.2	3.24	9 51	13.62	. . .
828	3049	ρ Ursæ Majoris . . .	4.9	51 42	5.52	65 05 43.7	13.66	− .01
829	3055	α Cancri	4.2	51 55	3.28	12 19 16.2	13.67	− .04
830	3056	σ^3 Cancri	5.1	52 10	3.70	32 53 01.5	13.69	− .06
831	3059	10 Ursæ Majoris . . .	4.1	8 52 51	+ 3.92	42 15 24.0	− 13.73	− .27
832	3072	Ursæ Majoris . . .	5.7	55 12	4.44	54 15 19.4	13.88	.00
833	3075	κ Ursæ Majoris . . .	3.5	55 25	4.12	47 37 46.2	13.89	− .11
834	3079	ν Cancri	5.2	55 43	3.52	24 55 24.6	13.91	− .07
835	3087	11 Ursæ Majoris . . .	5.1	57 50	5.36	67 21 11.5	14.04	− .06
836	3097	Ursæ Majoris . . .	4.7	58 54	3.85	38 55 49.7	14.11	− .06
837	3105	ω Hydræ	5.6	59 39	3.17	5 34 13.3	14.15	− .06
838	3099	σ Ursæ Majoris . . .	5.0	59 49	5.37	67 37 11.6	14.17	− .10
839	3106	f Ursæ Majoris . . .	4.9	9 00 24	4.27	52 05 15.6	14.20	− .05
840	3109	τ Cancri	5.8	00 48	3.62	30 08 07.3	14.23	− .05
841	3108	τ Ursæ Majoris . . .	4.9	9 01.00	+ 5.02	63 59 59.9	− 14.24	− .08
842	3111	κ Cancri	5.2	01 15	3.26	11 09 01.3	14.26	+ .02
843	3113	75 Cancri	5.7	01 44	3.55	27 07 28.4	14.28	− .08
844	3117	ξ Cancri	4.9	02 28	3.46	22 31 48.0	14.33	+ .02
845*	3116	Ursæ Majoris . . .	6.0	03 48	6.20	73 26 27.8	14.41	.00
846	3125	16 Ursæ Majoris (c) . .	5.1	04 51	4.82	61 54 57.3	14.47	− .09
847	3131	36 Lyncis	5.5	05 57	3.95	43 42 40.2	14.54	− .05
848	3135	17 Ursæ Majoris . . .	5.1	06 56	4.50	57 14 14.2	14.60	+ .07
849	3140	e Ursæ Majoris . . .	5.2	07 33	4.36	54 30 56.6	14.64	+ .02
850	3146	ϑ Hydræ	4.2	08 07	3.13	2 49 11.1	14.67	− .32

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
851	3147	π Cancri	5.8	9 08 36	+ 3.32	15 26 18.8	− 14.70	+ .02
852	3162	38 Lyncis	3.9	11 22	3.75	37 18 36.3	14.87	− .04
853	3172	Ursæ Majoris	5.7	12 54	4.45	57 12 23.6	14.96	.00
854	3178	40 Lyncis	3.3	13 44	3.67	34 53 55.2	15.01	− .02
855	3204	κ Leonis	4.4	17 40	3.51	26 41 52.0	15.23	− .03
856	3199	Draconis	4.3	19 51	9.14	81 51 16.6	15.35	+ .00
857	3218	Ursæ Majoris	5.4	20 48	3.96	46 07 34.5	15.41	− .13
858	3227	ω Leonis	5.4	22 02	3.22	9 34 41.9	15.48	− .02
859	3221	h Ursæ Majoris	3.6	22 03	4.80	63 35 07.8	15.48	+ .11
860	3228	3 Leonis	5.9	22 06	3.20	8 42 39.7	15.48	− .04
861	3231	22 Ursæ Majoris	5.8	9 23 32	+ 5.79	72 44 12.9	− 15.56	.00
862	3232	d Ursæ Majoris	4.9	23 51	5.42	70 21 22.4	15.57	+ .05
863	3241	S Leonis Minoris	5.6	24 14	3.67	35 37 59.0	15.60	− .10
864	3242	ϑ Ursæ Majoris	3.3	24 49	4.04	52 13 22.6	15.63	− .57
865	3246	λ Leonis	4.4	24 52	3.43	23 29 45.9	15.63	− .04
866	3250	ξ Leonis	5.1	25 29	3.24	11 49 49.3	15.65	− .08
867	3251	n Leonis	5.5	25 32	3.22	10 14 38.2	15.65	− .02
868	3253	τ² Hydræ	4.9	25 52	3.07	− 0 39 22.8	15.69	− .08
869	3256	26 Ursæ Majoris	4.8	26 36	4.15	52 35 03.0	15.73	− .04
870	3261	10 Leonis Minoris	4.5	26 52	3.70	36 55 46.0	15.74	+ .00
871	3265	Lyncis	4.9	9 27 34	+ 3.76	40 09 09.6	− 15.78	− .05
872	3268	11 Leonis Minoris	5.6	28 28	3.61	36 21 07.4	15.83	− .27
873	3273	Leonis	5.3	29 35	3.57	31 41 55.3	15.89	− .02
874	3286	1 Sextantis	5.5	30 52	3.17	7 22 23.2	15.96	.00
875	3281	42 Lyncis	5.4	30 52	3.77	40 46 39.5	15.96	.00
876	3283	27 Ursæ Majoris	5.2	31 52	5.67	72 47 46.3	16.01	− .05
877	3295	2 Sextantis	5.0	32 12	3.14	5 11 24.6	16.03	− .07
878	3284	D. M. 79, 319	5.8	33 00	7.47	79 41 07.0	16.07	.00
879	3303	ι Hydræ	4.2	33 44	3.07	− 0 35 57.4	16.10	− .11
880	3307	43 Lyncis	5.6	34 34	3.74	40 18 13.9	13.15	− .06
881	3312	14 Leonis (o)	3.6	9 34 45	+ 3.21	10 26 14.6	− 16.16	− .04
882	3317	Leonis	5.3	36 31	3.53	30 31 32.1	16.25	− .11
883	3321	ψ Leonis	5.8	37 12	3.28	14 34 09.8	16.28	− .04
884	3324	63 Ursæ Majoris	5.4	38 01	4.30	57 40 39.8	16.33	.00
885	3331	ε Leonis	3.2	39 02	3.42	24 19 33.2	16.38	− .02
886	3336	Sextantis	5.7	39 50	3.17	7 15 44.2	16.42	.00
887	3339	Sextantis	5.6	40 12	3.10	2 20 23.3	16.44	− .04
888	3341	Ursæ Majoris	5.0	40 51	3.91	46 34 45.2	16.47	− .10
889	3345	R Leonis	var. 5.2–1.0	41 06	3.23	11 59 01.5	16.48	− .17
890	3346	υ Ursæ Majoris	3.9	42 27	4.33	59 36 06.6	16.55	− .18
891	3358	φ Ursæ Majoris	4.8	9 43 56	+ 4.13	54 37 24.4	− 16.62	− .05
892	3366	g Leonis	5.5	45 04	3.42	24 57 44.2	16.68	− .20
893	3371	μ Leonis	3.9	45 56	3.42	26 34 16.9	16.72	− .06
894	3374	7 Sextantis	5.8	46 01	3.10	3 00 47.8	16.72	+ .11
895	3381	31 Ursæ Majoris	5.4	47 52	3.95	50 23 07.5	16.81	.00
896	3399	19 Leonis Minoris	5.2	50 20	3.70	41 37 35.4	16.93	.00
897	3402	Ursæ Majoris	5.1	51 35	4.18	57 23 07.3	16.99	.00
898	3406	ν Leonis	5.5	51 46	3.23	13 00 59.9	17.00	− .01
899	3409	Leonis	5.6	52 41	3.50	30 13 06.7	17.04	− .13
900	3415	π Leonis	4.9	53 52	3.18	8 37 09.5	17.09	− .03

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
901	3416	20 Leonis Minoris . . .	5.4	9 54 05	+ 3.47	32 30 47.2	− 17.09	− .45
902	3423	Leonis	5.3	56 07	3.36	22 31 38.6	17.19	− .01
903	3446	21 Leonis Minoris . . .	4.3	10 00 21	3.56	35 49 43.9	17.38	+ .01
904	3453	η Leonis	3.5	00 47	3.28	17 20 50.0	17.40	+ .01
905	3457	A Leonis	4.8	01 32	3.19	10 35 06.5	17.43	− .05
906	3458	15 Sextantis	4.4	01 48	3.08	0 12 52.0	17.44	− .01
907	3459	α Leonis	1.2	01 59	3.20	12 33 11.3	17.45	+ .01
908	3468	Leonis Minoris . . .	6.0	04 06	3.58	37 59 34.1	17.53	.00
909	3496	32 Ursæ Majoris . . .	5.7	09 18	4.43	65 42 20.9	17.76	− .04
910	3500	23 Leonis Minoris . . .	5.8	09 25	3.43	29 54 26.1	17.76	− .11
911	3505	λ Ursæ Majoris . . .	3.4	10 09 51	+ 3.64	43 30 46.3	− 17.78	− .06
912	3508	ζ Leonis	3.4	10 01	3.35	24 00 54.0	17.79	+ .02
913	3510	37 Leonis	5.5	10 14	3.23	14 19 33.4	17.79	− .02
914	3514	Ursæ Majoris . . .	5.8	11 53	4.67	69 20 59.0	17.86	− .06
915	3495	Camelopardalis . . .	5.0	11 58	9.73	84 51 35.7	17.87	− .05
916*	. .	Ursæ Majoris . . .	6.1	12 . .	3.77	49 00	17.87	. . .
917	3522	40 Leonis	5.8	13 12	3.28	20 04 45.1	17.92	− .23
918	3523	γ Leonis (1st star) . .	2.2	13 21	3.31	20 26 52.6	17.92	− .12
919	3533	μ Ursæ Majoris . . .	3.2	15 11	3.60	42 06 09.2	17.99	+ .03
920	3531	Ursæ Majoris . . .	4.9	15 28	4.40	66 10 19.6	18.00	− .06
921	3542	27 Leonis Minoris . . .	5.8	10 16 12	+ 3.48	34 30 46.5	− 18.03	− .09
922	3528	Camelopardalis . . .	5.0	16 18	7.92	83 10 03.3	18.04	− .07
923	3548	28 Leonis Minoris . . .	5.6	17 15	3.47	34 19 28.9	18.07	− .07
924	3561	44 Leonis	5.9	18 56	3.16	9 23 38.0	18.14	− .12
925	3560	30 Leonis Minoris . . .	4.5	19 02	3.46	34 24 23.2	18.14	− .08
926	3572	31 Leonis Minoris . . .	4.3	20 56	3.49	37 19 17.4	18.21	− .10
927	3580	36 Ursæ Majoris . . .	4.7	22 57	3.89	56 35 44.1	18.23	+ .01
928	3590	29 Sextantis	5.0	23 23	3.05	− 2 07 33.1	18.30	− .04
929	3597	30 Sextantis	5.0	24 09	3.07	− 0 01 21.0	18.32	− .03
930	3593	Draconis	4.8	24 51	5.29	76 19 48.4	18.34	− .03
931	3606	i Leonis	5.7	10 25 48	+ 3.21	14 45 08.1	− 18.38	− .04
932	3607	Ursæ Majoris . . .	4.9	26 14	3.53	41 02 33.2	18.40	.00
933	3609	ρ Leonis	4.1	26 30	3.16	9 55 24.9	18.40	+ .00
934	3610	34 Leonis Minoris . . .	5.8	26 39	3.45	35 36 22.5	18.41	− .02
935	3612	37 Ursæ Majoris . . .	5.0	27 25	3 91	57 41 58.4	18.44	− .03
936	3639	Ursæ Majoris . . .	5.8	31 39	3.78	54 17 40.3	18.58	.00
937	3640	37 Leonis Minoris . . .	4.7	31 58	3.40	32 35 56.9	18.59	.00
938	3641	38 Leonis Minoris . . .	6.0	32 16	3.45	38 32 06.1	18.60	− .03
939	3645	Ursæ Majoris . . .	5.6	33 15	4.37	69 04 10.2	18.63	. . .
940	3647	38 Ursæ Majoris . . .	5.0	33 45	4.18	66 20 39.0	18.65	− .10
941	3652	Ursæ Majoris . . .	4.9	10 34 28	+ 4.40	69 42 10.6	− 18.67	− .05
942	3664	39 Ursæ Majoris . . .	5.5	36 08	3.84	57 49 43.1	18.72	− .07
943	3666	40 Leonis Minoris . . .	5.3	36 27	3.31	26 57 19.6	18.74	− .06
944	3665	Ursæ Majoris . . .	5.3	36 29	3.55	46 50 03.3	18.74	+ .03
945	3671	41 Leonis Minoris . . .	5.2	36 53	3.28	23 48 58.1	18.75	− .01
946	3685	42 Leonis Minoris . . .	5.0	39 11	3.35	31 18 50.3	18.82	− .03
947*	3691	m Leonis	5.5	39 57	3.24	19 31 24.6	18.84	− .08
948	3693	k Leonis	5.5	40 04	3.18	14 49 38.8	18.84	− .10
949	3708	l Leonis	5.2	42 57	3.16	11 10 48.1	18.93	− .00
950	3714	42 Ursæ Majoris . . .	5.7	43 51	3.83	59 57 23.5	18.96	− .09

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
951	. .	Ursæ Majoris	5.8	10 45 19	+ 4.27	70 29 35.7	− 19.00	...
952	. .	Ursæ Majoris (sq.)	5.9	45 20	3.65	53 08 31.7	19.00	...
953	3725	44 Ursæ Majoris	5.4	46 18	3.68	55 13 20.0	19.02	− .04
954	3728	46 Leonis Minoris	4.0	46 36	3.37	34 51 41.8	19.03	− .25
955	3729	ω Ursæ Majoris	4.9	47 04	3.48	43 49 41.7	19.04	− .06
956	3732	p¹ Leonis	5.4	47 37	3.06	− 1 29 32.1	19.06	.00
957	3741	46 Ursæ Majoris	5.3	49 05	3.34	34 08 50.0	19.10	− .06
958	3742	54 Leonis	4.3	49 07	3.27	25 23 22.6	19.10	− .01
959*	. .	Ursæ Majoris	5.8	52.2	3.58	52 32	19.18	...
960	3757	47 Ursæ Majoris	5.1	52 45	3.38	41 04 14.5	19.19	+ .06
961*	. .	Ursæ Majoris	5.8	10 52 51	+ 3.36	36 44 16.8	− 19.19	...
962	3758	Ursæ Majoris	5.5	53 21	3.47	46 10 09.0	19.21	.00
963	3765	49 Ursæ Majoris	5.1	54 07	3.39	39 51 23.0	19.23	− .02
964	3768	d Leonis	4.6	54 22	3.10	4 15 41.2	19.24	− .03
965	3769	c Leonis	5.2	54 32	3.11	6 44 44.5	19.24	− .06
966	3767	β Ursæ Majoris	2.3	54 35	3.66	57 01 30.9	19.24	+ .03
967	3775	p² Leonis	5.0	55 42	3.06	− 1 50 20.4	19.27	− .04
968	3776	b Leonis	4.4	55 55	3.21	20 49 23.3	19.27	+ .03
969	3777	α Ursæ Majoris	1.9	56 19	3.76	62 23 53.8	19.28	− .09
970	3788	χ Leonis	4.8	58 50	3.10	7 59 02.6	19.34	− .08
971	3798	p⁴ Leonis	5.7	11 00 47	+ 3.06	2 36 24.5	− 19.39	− .08
972	3809	67 Leonis	5.6	02 23	3.23	25 18 27.2	19.42	− .01
973	3811	Ursæ Majoris	5.7	02 43	3.33	36 57 37.2	19.43	− .02
974	3812	ψ Ursæ Majoris	3.1	02 55	3.40	45 08 55.5	19.43	− .08
975	3832	p⁵ Leonis	5.2	07 37	3.08	0 34 59.0	19.53	.00
976	3834	δ Leonis	2.5	07 43	3.20	21 10 51.4	19.53	− .14
977	3838	ϑ Leonis	3.3	07 57	3.16	16 05 07.4	19.54	− .03
978	3842	72 Leonis	4.9	08 49	3.20	23 44 57.6	19.55	− .01
979	3843	n Leonis	5.3	09 35	3.15	13 57 41.5	19.57	− .04
980	3846	Ursæ Majoris	5.5	09 56	3.42	50 07 51.0	19.58	− .01
981	3850	75 Leonis	5.4	11 11 07	+ 3.09	2 40 11.4	− 19.59	− .18
982	3851	ξ Ursæ Majoris (1st *)	3.9	11 47	3.21	32 12 16.4	19.61	− .57
983	3852	ν Ursæ Majoris	3.5	12 00	3.26	33 44 56.7	19.61	+ .04
984	3856	55 Ursæ Majoris	4.8	12 35	3.29	38 50 37.1	19.62	− .08
985	3862	σ Leonis	4.3	14 57	3.11	6 41 11.9	19.67	− .03
986	3864	Ursæ Majoris	6.0	15 43	3.62	64 59 10.3	19.68	− .06
987	3868	56 Ursæ Majoris	5.0	16 14	3.32	44 08 24.4	19.69	− .07
988	3877	ι Leonis	4.0	17 40	3.13	11 11 24.5	19.71	− .06
989	3879	79 Leonis	5.6	17 53	3.08	2 03 57.7	19.72	− .02
990	3886	81 Leonis	5.8	19 21	3.14	17 06 57.8	19.74	.00
991	3900	τ Leonis	4.9	11 21 46	+ 3.09	3 31 00.9	− 19.77	− .02
992	3905	57 Ursæ Majoris	5.3	22 36	3.25	39 59 49.4	19.79	− .01
993	3915	86 Leonis	5.5	24 13	3.14	19 04 13.5	19.81	+ .01
994	3914	λ Draconis	3.8	24 16	3.63	69 59 34.6	19.81	− .06
995	3918	Ursæ Majoris	5.8	25 32	3.45	61 44 54.1	19.82	.00
996	3932	90 Leonis	5.7	28 28	3.13	17 27 35.0	19.87	+ .01
997	3931	Ursæ Majoris	5.8	28 28	3.35	55 26 53.3	19.87	.00
998	3933	2 Draconis	5.2	29 00	3.58	69 59 26.3	19.87	− .10
999	3937	Leonis	5.6	29 59	3.16	28 26 38.2	19.88	− .05
1000	3946	υ Leonis	4.7	30 48	3.07	− 0 09 41.2	19.89	+ .05

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1001	3949	Ursæ Majoris . . .	6.3	11 31 23	+ 3.28	51 17 00.0	− 19.90	.00
1002	2952	59 Ursæ Majoris . . .	5.5	31 57	3.22	44 17 25.5	19.90	− .08
1003	3964	92 Leonis	5.2	34 33	3.13	22 01 08.8	19.93	+ .01
1004	3965	61 Ursæ Majoris . . .	5.1	34 44	3.17	34 52 46.0	19.93	− .41
1005	3966	62 Ursæ Majoris . . .	5.8	35 19	3.14	32 24 37.8	19.94	+ .03
1006	3968	3 Draconis	5.1	35 46	3.41	67 24 32.5	19.94	+ .06
1007	3979	ξ Virginis	4.8	39 06	3.09	8 55 30.7	19.97	− .02
1008	3982	ν Virginis	4.3	39 41	3.09	7 12 06.0	19.97	− .21
1009	3981	χ Ursæ Majoris . . .	3.8	39 43	3.20	48 26 41.1	19.97	+ .02
1010	3985	Ursæ Majoris . . .	5.5	40 30	3.24	56 17 46.1	19.98	.00
1011	3989	A¹ Virginis	5.8	11 41 45	+ 3.09	8 54 43.6	− 19.99	− .02
1012	3990	93 Leonis	4.2	41 48	3.12	20 53 09.0	19.99	.00
1013	3995	β Leonis	2.1	42 56	3.06	15 14 34.5	20.00	− .10
1014	3998	Ursæ Majoris . . .	5.5	43 28	3.14	35 35 54.1	20.00	− .03
1015	4002	β Virginis	3.7	44 27	3.12	2 26 27.0	20.01	− .28
1016	4017	γ Ursæ Majoris . . .	2.4	47 31	3.18	54 21 42.3	20.02	.00
1017	4027	A² Virginis	5.6	48 54	3.08	9 06 39.5	20.03	− .02
1018	4031	o Leonis	5.5	49 30	3.09	16 18 53.0	20.03	+ .06
1019	4033	66 Ursæ Majoris . . .	5.8	49 42	3.17	57 15 58.6	20.03	− .02
1020*	. .	Ursæ Majoris . . .	6.0	52 . .	3.11	33 49	20.04	.00
1021	4049	b Virginis	5.5	11 53 48	+ 3.07	4 19 24.8	− 20.04	− .02
1022	4052	π Virginis	4.4	54 43	3.08	7 16 59.9	20.05	− .04
1023	. .	184 Ursæ Majoris . . .	5.6	55 31	3.10	36 42 48.8	20.05	. . .
1024	4057	67 Ursæ Majoris . . .	5.1	56 01	3.07	43 42 39.4	20.05	+ .02
1025	4066	2 Comæ	5.8	58 08	3.08	22 07 39.5	20.05	+ .01
1026	4070	Camelopardalis . . .	5.9	58 42	3.19	86 15 07.8	20.05	+ .04
1027	4072	9 Virginis (o)	4.2	59 06	3.06	9 23 59.0	20.05	+ .05
1028	. .	Draconis	5.5	59 08	3.14	77 34 36.7	20.05	. . .
1029	4074	Ursæ Majoris . . .	5.8	59 36	3.08	63 36 15.0	20.05	.00
1030	4099	3 Comæ.	6.0	12 04 25	3.06	17 28 38.6	20.05	+ .01
1031	4100	Comæ	6.0	12 04 40	+ 3.07	27 56 57.7	− 20.05	− .02
1032	4107	4 Comæ	5.6	05 46	3.06	26 32 21.0	20.05	+ .01
1033	4110	5 Comæ	5.8	06 03	3.06	21 12 35.8	20.05	+ .02
1034	4112	Draconis	4.8	06 34	2.89	78 16 58.7	20.04	− .01
1035	4122	Draconis	5.6	09 25	2.91	70 52 05.8	20.04	.00
1036	4123	δ Ursæ Majoris . . .	3.3	09 29	3.00	57 41 56.1	20.04	− .06
1037	4125	6 Comæ	5.0	09 55	3.06	15 34 02.3	20.04	− .01
1038	4126	2 Canum Venaticorum .	5.3	10 07	3.02	41 19 42.8	20.03	− .03
1039	4127	7 Comæ	5.2	10 16	3.04	24 36 44.8	20.03	.00
1040	4128	Canum Venaticorum .	5.0	10 28	3.04	33 43 55.7	20.03	− .18
1041*	. .	Comæ	5.7	12 11.5	+ 3.03	29 37	− 20.03	. . .
1042	4143	Draconis	5.5	13 27	2.79	75 49 36.8	20.02	+ .02
1043	4145	η Virginis	3.5	13 46	3.06	0 00 00.9	20.02	− .01
1044	4148	3 Canum Venaticorum .	5.5	13 54	2.98	49 39 00.1	20.02	− .06
1045	4151	c Virginis	5.0	14 15	3.05	3 58 52.0	20.02	− .07
1046	4153	D. M. 27°, 2114 . . .	4.9	14 18	3.03	27 17 23.4	20.02	.00
1047*	. .	D. M. 27°, 2115 . . .	5.8	14.6	3.03	27 44	20.02	. . .
1048	4156	11 Comæ	4.6	14 39	3.04	18 27 21.9	20.01	+ .07
1049	4159	70 Ursæ Majoris . . .	5.8	15 02	2.94	58 31 57.2	20.01	− .06
1050	4169	12 Comæ	5.0	16 28	3.02	26 30 44.6	20.00	+ .01

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1051	4180	5 Canum Venaticorum	5.1	12 18 11	+ 2.94	52 13 37.1	− 19.99	− .02
1052	4181	13 Comæ	5.3	18 17	3.02	26 45 50.9	19.99	− .02
1053	4184	Comæ	6.0	19 13	3.04	24 35 31.4	19.98	− .14
1054	. .	D. M. 64°, 896	5.8	19 30	2.83	64 28 03.7	19.98	...
1055	4188	6 Canum Venaticorum	4.9	19 56	2.97	39 41 02.8	19.98	− .09
1056	4191	14 Comæ	5.0	20 24	3.01	27 55 59.4	19.97	− .02
1057	4195	15 Comæ	4.5	20 57	3.00	28 56 08.3	19.97	− .10
1058	4196	16 Comæ	5.1	20 59	3.01	27 29 25.7	19.97	.00
1059	4203	73 Ursæ Majoris	5.6	21 52	2.88	56 22 36.8	19.96	− .05
1060	4207	17 Comæ	5.6	22 55	3.01	26 34 39.4	19.95	− .01
1061	4209	18 Comæ	5.6	12 23 27	+ 3.01	24 46 17.8	− 19.95	− .08
1062	4212	20 Comæ	5.7	23 42	3.03	21 33 40.0	19.94	.00
1063	4216	74 Ursæ Majoris	5.5	24 21	2.83	59 03 57.3	19.94	+ .06
1064	4222	4 Draconis	4.8	24 51	2.68	69 51 57.0	19.93	− .09
1065	4223	21 Comæ	5.3	25 01	3.01	25 13 50.0	19.93	− .05
1066	4233	Canum Venaticorum	5.4	27 44	3.02	33 54 39.0	19.91	− .07
1067	4235	8 Canum Venaticorum	4.4	28 02	2.86	42 00 35.4	19.90	+ .30
1068	4239	κ Draconis	3.8	28 21	2.60	70 26 57.8	19.90	− .03
1069	4240	23 Comæ	5.1	28 52	3.01	23 17 25.1	19.99	.00
1070	4242	24 Comæ	4.6	29 07	3.02	19 02 16.0	19.89	.00
1071	4246	6 Draconis	5.0	12 29 39	+ 2.60	70 40 59.5	− 19.89	− .02
1072	4248	25 Comæ	5.7	30 57	3.02	17 45 03.1	19.87	− .04
1073	4254	Virginis	5.8	32 15	3.06	2 30 54.2	19.85	− .09
1074	. .	R Virginis	var. 6.4–11.	32 25	3.05	7 38 55.4	19.85	...
1075	4260	26 Comæ	5.6	33 09	2.99	21 43 22.7	19.84	+ .01
1076	. .	Canum Venaticorum	5.8	33 26	2.93	36 36 42.4	19.84	.00
1077†	4268	γ Virginis	2.8	35 35	3.03	− 0 47 30.2	19.81	− .05
1078	4271	ρ Virginis	5.0	35 49	3.03	10 53 50.2	19.81	− .10
1079	4274	31 Virginis (d¹)	5.8	35 52	3.04	7 27 55.5	19.81	− .04
1080	4287	Canum Venaticorum	5.0	39 29	2.83	46 05 46.9	19.76	.00
1081	4286	d² Virginis	5.8	12 39 33	+ 3.04	8 19 46.4	− 19.75	− .04
1082	4290	27 Comæ	5.0	40 39	3.00	17 13 59.3	19.74	+ .01
1083	4300	Ursæ Majoris	5.8	42 11	2.58	63 26 11.4	19.71	.00
1084	4302	7 Draconis	5.3	42 40	2.52	67 26 44.7	19.71	+ .01
1085	4301	29 Comæ	5.6	42 53	3.01	14 46 40.0	19.70	− .06
1086*	. .	Comæ	6.0	43 ..	2.95	25 30	19.70	...
1087	4303	11 Canum Venaticorum	6.1	43 11	2.80	49 07 14.9	19.70	− .05
1088	4305	Ursæ Majoris	6.0	43 25	2.62	60 58 28.4	19.69	.00
1089	4311	Canum Venaticorum	5.8	44 29	2.87	38 10 12.5	19.68	.00*
1090	4315	31 Comæ	5.0	45 51	2.93	28 11 39.7	19.65	.00
1091	4328	35 Comæ	5.0	12 47 23	+ 2.96	21 53 50.9	− 19.63	− .04
1092	4329	41 Virginis	5.8	47 49	3.01	13 04 15.4	19.62	− .05
1093	4342	Camelopardalis (sq.)	5.2	48 15	0.37	84 03 53.6	19.61	− .02
1094	4335	ε Ursæ Majoris	1.7	48 45	2.66	56 36 39.4	19.60	− .06
1095	4341	Canum Venaticorum	5.7	49 28	2.75	47 50 52.4	19.59	.00
1096	4340	δ Virginis	3.6	49 34	3.02	4 02 58.9	19.59	− .09
1097	4346	12 Canum Venaticorum	2.8	50 25	2.81	38 58 00.4	19.57	+ .06
1098	4347	8 Draconis	4.9	50 42	2.42	66 05 22.4	19.56	− .06
1099	4351	36 Comæ	4.9	52 59	2.97	18 03 24.9	19.52	+ .06
1100	4360	37 Comæ	5.0	54 32	2.88	31 25 58.4	19.49	.00

† Double. South star.

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1101	. .	Draconis	6.0	12 55 15	+ 1.78	76 07 09.5	− 19.47	.00
1102	4365	9 Draconis	5.4	55 23	2.29	67 14 41.0	19.47	− .02
1103	4366	78 Ursæ Majoris . . .	5.6	55 35	2.59	57 00 49.3	19.47	+ .02
1104	4367	ε Virginis	3.0	56 12	2.99	11 36 16.2	19.45	+ .03
1105	4371	Draconis	5.8	57 06	2.38	64 15 18.3	19.43	+ .02
1106	. .	Canum Venaticorum .	5.8	58 25	2.75	43 39 08.6	19.41	.00
1107	4384	14 Canum Venaticorum .	5.3	13 00 08	2.82	36 26 28.9	19.37	.00
1108	4389	Canum Venaticorum .	5.4	00 28	2.71	45 54 37.0	19.36	.00
1109	4387	39 Comæ	5.8	00 30	2.93	21 47 51.2	19.36	− .03
1110	4388	40 Comæ	5.7	00 32	2.93	23 15 38.5	19.36	+ .02
1111	. .	Ursæ Minoris . . .	6.0	13 01 07	+ 1.87	73 40 03.0	− 19.35	.00
1112	4390	41 Comæ	4.9	01 25	2.88	28 16 07.7	19.34	− .09
1113	4392	Ursæ Majoris . . .	6.0	01 39	2.39	62 41 08.4	19.33	− .03
1114	4407	Canum Venaticorum .	6.0	04 07	2.78	38 03 46.5	19.27	.00
1115	4406	42 Comæ	4.8	04 09	2.92	18 09 52.0	19.27	+ .13
1116	4421	43 Comæ	4.7	06 16	2.81	28 29 13.2	19.22	+ .91
1117	4423	Virginis	6.0	06 35	2.99	12 11 41.4	19.21	− .04
1118	4433	Canum Venaticorum .	4.9	08 16	2.73	40 47 17.2	19.17	− .06
1119	4438	19 Canum Venaticorum .	5.8	10 08	2.72	41 29 22.0	19.12	+ .02
1120	4440	e Virginis	5.6	10 49	2.98	10 03 05.7	19.10	+ .19
1121	4444	Virginis	5.4	13 11 20	+ 2.97	14 18 25.8	− 19.09	−0.11
1122	4446	σ Virginis	5.0	11 33	3.03	6 06 10.4	19.08	+ .06
1123	4451	20 Canum Venaticorum .	4.8	12 10	2.70	41 12 18.5	19.07	+ .03
1124*	. .	Draconis	6.0	12.5	1.99	69 02	19.06	...
1125	4456	21 Canum Venaticorum .	5.1	13 08	2.57	50 18 47.3	19.04	− .03
1126	4467	23 Canum Venaticorum .	5.6	14 56	2.70	40 46 51.5	18.99	− .01
1127*	4470	Virginis	5.5	15.6	3.05	2 43	18.97	...
1128	4479	D. M. 37°, 2404 . . .	5.8	18 27	2.72	37 39 40.2	18.89	.00
1129	4484	ζ Ursæ Majoris . . .	2.0	19 06	2.43	55 33 08.2	18.87	− .04
1130	. .	Comæ	5.6	19 23	2.86	24 28 49.8	18.86	...
1131	4493	80 Ursæ Majoris (g) . .	4.9	13 20 25	+ 2.42	55 36 48.3	− 18.83	− .03
1132	. .	Canum Venaticorum .	5.8	21 07	2.58	46 39 11.8	18.81	.00
1133	4499	70 Virginis	5.3	22 34	2.93	14 25 11.9	18.76	− .57
1134	4506	Ursæ Minoris . . .	5.5	23 04	1.52	73 00 52.8	18.75	− .03
1135	4510	Ursæ Majoris . . .	5.2	24 03	2.21	60 33 54.5	18.72	− .02
1136	4527	Camelopardalis . . .	5.8	25 57	0.45	79 15 49.9	18.66	+ .02
1137	4526	Comæ	6.0	27 07	2.84	24 58 15.1	18.62	.00
1138	4529	78 Virginis (o)	4.9	28 03	3.03	4 16 32.3	18.59	− .04
1139	4532	ζ Virginis	3.4	28 35	3.05	0 01 05.8	18.57	+ .06
1140	4536	Canum Venaticorum .	5.3	29 26	2.68	37 47 48.5	18.54	− .09
1141	4540	81 Ursæ Majoris . . .	5.8	13 29 31	+ 2.32	55 57 49.5	− 18.54	− .02
1142	4538	24 Canum Venaticorum .	4.7	29 33	2.46	49 37 46.7	18.54	− .02
1143*	. .	Comæ	5.8	31.3	2.83	25 13	18.48	...
1144	4552	25 Canum Venaticorum .	5.1	32 08	2.68	36 54 20.2	18.45	.00
1145	. .	Camelopardalis . . .	6.0	32 20	0.81	77 09 33.8	18.45	...
1146	4559	Bootis	5.2	33 40	2.97	11 21 22.5	18.40	.00
1147	. .	Ursæ Minoris . . .	5.7	34 18	1.44	71 51 10.7	18.38	.00
1148*	. .	Canum Venaticorum .	5.8	34.8	2.74	31 37	18.36	...
1149	4564	82 Ursæ Majoris . . .	5.5	34 52	2.33	53 31 39.9	18.36	− .01
1150	4562	1 Bootis	5.4	34 57	2.87	20 33 47.1	18.36	+ .02

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1151	4566	2 Bootis	5.5	13 35 22	+ 2.84	23 06 15.6	− 18.34	+ .01
1152	4568	83 Ursæ Majoris	5.3	36 11	2.28	55 17 19.7	18.31	− .05
1153	4570	84 Virginis	5.5	37 02	3.01	4 08 44.9	18.28	− .08
1154	. .	Canum Venaticorum	6.2	37 22	2.57	42 16 46.0	18.27	...
1155	4577	Draconis	5.8	37 45	1.86	65 25 35.1	18.25	− .27
1156	4595	D. M. 39°, 2678	5.9	41 07	2.61	39 06 18.8	18.13	.00
1157	4596	Canum Venaticorum	6.0	41 08	2.56	41 41 30.6	18.13	.00
1158	4594	3 Bootis	5.8	41 09	2.79	26 18 18.7	18.13	− .01
1159	4597	τ Bootis	4.5	41 34	2.85	18 03 20.3	18.12	+ .05
1160	4600	Canum Venaticorum	5.6	41 50	2.60	39 08 37.6	18.11	...
1161	4614	D. M. 78°, 466	5.6	13 42 10	+ 0.18	78 39 55.5	− 18.09	+ .07
1162	4607	η Ursæ Majoris	1.8	42 49	2.37	49 54 45.2	18.07	− .03
1163	4610	Canum Venaticorum	5.6	43 14	2.71	31 47 10.6	18.05	.00
1164	4615	υ Bootis	4.3	43 41	2.89	16 23 38.3	18.04	+ .05
1165	4618	e Bootis	4.9	44 02	2.84	21 51 38.2	18.02	+ .16
1166*	4628	Canum Venat. (sq.)	5.4	45 51	2.65	35 15 41.2	17.95	...
1167	. .	Draconis	5.8	45 51	1.95	62 05 20.7	17.95	.00
1168	4632	Canum Venaticorum	5.2	46 30	2.65	35 02 21.6	17.92	.00
1169	4640	Canum Venaticorum	5.8	47 44	2.74	29 14 19.2	17.88	− .12
1170	4646	i Draconis	4.8	47 56	2.76	65 18 58.2	17.87	− .04
1171	. .	Ursæ Minoris	6.0	13 48 04	+ 1.50	68 54 39.0	− 17.87	...
1172	4648	η Bootis	2.9	48 58	2.86	18 59 59.9	17.83	− .33
1173	4649	86 Ursæ Majoris	5.8	49 26	2.22	54 19 05.7	17.81	− .11
1174	4651	92 Virginis	5.7	50 21	3.05	1 38 17.5	17.78	+ .03
1175	4656	9 Bootis	5.0	51 05	2.74	28 04 51.6	17.75	− .05
1176	4664	10 Bootis	5.6	53 01	2.81	22 16 56.5	17.66	− .02
1177*	. .	Bootis	5.8	55.4	2.96	9 29	17.56	...
1178	4672	τ Virginis	4.2	55 32	3.05	2 07 32.3	17.56	− .07
1179*	. .	Canum Venaticorum	6.4	57.4	2.39	46 20	17.48	...
1180	4684	Bootis	6.2	58 32	2.25	51 32 54.6	17.43	− .09
1181	4696	α Draconis	3.8	14 01 08	+ 1.62	64 56 57.6	− 17.32	− .03
1182	4699	Bootis	5.2	03 08	2.41	44 25 30.5	17.23	− .12
1183	4701	13 Bootis	5.2	03 48	2.24	50 01 29.8	17.20	− .03
1184	4706	d Bootis	4.8	04 56	2.74	25 39 39.2	17.15	− .05
1185	. .	D. M. 60°, 1516	5.8	05 03	1.87	59 54 23.7	17.14	...
1186	4713	Virginis	4.7	06 11	3.04	2 58 29.5	17.08	− .04
1187	4724	15 Bootis	5.5	08 58	2.94	10 39 59.5	16.96	− .17
1188	4726	κ Bootis	4.5	09 11	2.16	52 21 04.5	16.95	− .02
1189	4733	4 Ursæ Minoris	5.0	09 21	− 0.33	78 06 39.2	16.94	− .01
1190	4732	Ursæ Minoris	5.3	09 49	+ 1.02	69 59 44.9	16.92	− .06
1191	4729	α Bootis	0.2	14 10 11	+ 2.73	19 48 29.7	− 16.90	−1.93
1192	4741	λ Bootis	4.2	11 49	2.29	46 38 22.9	16.83	+ .13
1193	4742	ι Bootis	4.8	11 55	2.13	51 55 16.0	16.82	+ .07
1194	4747	A Bootis	4.8	12 55	2.53	36 03 49.5	16.77	.00
1195	4748	υ Virginis	4.9	13 22	3.09	− 1 42 36.0	16.75	− .09
1196	4751	18 Bootis	5.5	13 28	2.90	13 33 34.0	16.75	+ .07
1197	4753	20 Bootis	5.2	14 05	2.84	16 51 26.9	16.72	+ .10
1198	4758	Bootis	5.9	14 52	2.46	39 20 46.3	16.68	.00
1199	4766	Bootis	4.9	17 29	2.96	8 59 34.8	16.55	− .06
1200	4773	Bootis	5.2	18 13	2.98	6 21 55.0	16.52	+ .03

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s	° ′ ″	″	″
1201	4789	ϑ Bootis.	4.2	14 21 07	+ 2.04	52 24 21.1	− 16.37	− .41
1202	4792	φ Virginis	4.9	22 01	3.09	− 1 41 21.2	16.32	− .02
1203	4804	24 Bootis (g).	5.7	24 27	2.09	50 22 55.9	16.20	− .09
1204	4808	ρ Bootis.	3.8	26 39	2.59	30 53 56.7	16.09	+ .14
1205	4810	26 Bootis.	5.4	27 05	2.72	22 47 19.8	16.06	+ .05
1206	4812	γ Bootis.	3.1	27 15	2.42	38 50 01.1	16.05	+ .14
1207	4822	5 Ursæ Minoris . . .	4.6	27 48	− 0.20	76 13 44.3	16.02	− .02
1208*	. .	Draconis	5.7	28.8	+ 1.88	55 56	15.97	...
1209	4823	σ Bootis.	4.9	29 27	2.61	30 16 01.5	15.94	+ .12
1210	4830	Bootis.	5.9	30 28	2.10	49 53 29.9	15.88	.00
1211	4841	Bootis.	5.8	14 33 42	+ 2.26	44 09 36.1	− 15.71	.00
1212	4843	33 Bootis.	5.4	34 22	2.23	44 55 21.8	15.68	− .10
1213	4845	Bootis.	5.7	34 28	1.90	54 32 31.6	15.67	− .06
1214*	. .	Bootis.	6.0	34.9	2.73	22 30	15.65	...
1215	4847	π Bootis, (1st *) . . .	4.1	35 05	2.82	16 56 01.8	15.64	+ .02
1216	4849	ζ Bootis.	3.7	35 25	2.86	14 14 38.7	15.62	.00
1217	4850	31 Bootis.	5.1	35 45	2.99	8 40 32.7	15.60	− .02
1218	4853	32 Bootis.	5.4	35 58	2.89	12 10 44.7	15.58	− .07
1219	4864	34 Bootis.	5.4	38 09	2.64	27 02 20.9	15.47	+ .01
1220	4874	Draconis	5.8	39 04	1.48	61 46 26.9	15.42	.00
1221*	. .	Virginis	6.0	14 39 00	+ 3.09	− 0 54	− 15.42	...
1222	4870	Bootis.	5.4	39 05	2.33	40 58 03.3	15.41	.00
1223	4873	ο Bootis.	4.5	39 38	2.80	17 28 24.2	15.38	− .04
1224	4876	ε Bootis.	2.6	39 45	2.62	27 34 51.6	15.38	− .03
1225	4878	109 Virginis	3.9	40 11	3.03	2 23 57.8	15.35	− .02
1226*	. .	Bootis.	5.6	40.5	2.83	15 38	15.33	...
1227	4898	11 Libræ	5.1*	44 48	3.10	− 1 47 53.5	15.09	− .14
1228*	. .	Bootis.	5.7	44.9	2.67	24 25	15.09	...
1229	4903	38 Bootis (h)	5.8	45 02	2.14	46 37 01.0	15.08	− .09
1230	4907	39 Bootis.	5.7	45 37	2.04	49 12 52.1	15.04	+ .02
1231	4906	Bootis.	5.6	14 45 46	+ 2.38	37 45 52.0	− 15.03	.00
1232	4905	ξ Bootis, (2d *). . . .	4.7	45 51	2.77	19 35 57.8	15.02	− .14
1233	4918	Draconis	5.5	48 24	1.52	59 46 54.3	14.88	+ .07
1234	4936	β Ursæ Minoris . . .	2.2	51 04	− 0.25	74 38 44.2	14.72	− .03
1235	4931	Libræ	6.0	51 24	+ 3.07	0 18 59.8	14.70	− .04
1236	4937	Bootis.	5.8	52 25	2.01	50 07 09.7	14.64	− .27
1237	4943	40 Bootis.	5.4	55 01	2.30	39 44 30.8	14.49	+ .03
1238	4949	Ursæ Minoris . . .	4.6	55 41	0.94	66 24 38.2	14.44	+ .05
1239	4951	40 Virginis	4.7	56 50	3.03	2 33 49.3	14.38	+ .01
1240	4953	ω Bootis.	4.7	56 51	2.63	25 28 59.6	14.38	− .06
1241	4958	β Bootis.	3.6	14 57 26	+ 2.26	40 51 52.2	− 14.34	− .04
1242	4961	Bootis.	5.7	58 19	2.41	35 40 35.7	14.29	.00
1243	4982	Camelopardalis . . .	5.8	58 31	− 4.58	83 00 16.5	14.27	.00
1244*	4967	Draconis	5.8	58 39	+ 1.38	60 40 33.5	14.27	...
1245	4969	ψ Bootis.	4.6	59 18	2.57	27 24 59.1	14.22	− .01
1246	4974	i Bootis.	4.8	59 50	1.98	48 07 18.1	14.19	+ .03
1247	4980	k Bootis.	5.8	15 01 27	1.98	48 36 54.2	14.08	.00
1248	4981	c Bootis.	5.0	02 02	2.63	25 20 14.8	14.06	− .16
1249	4989	Ursæ Minoris . . .	5.7	02 08	0.89	66 23 09.3	14.05	.00
1250	4992	Draconis	5.2	02 51	1.70	55 01 07.4	14.01	.00

*Suspected variable, D. M. 4.4, 𝔇 5.8.

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1251	. .	Bootis	5.7	15 06 37	+ 2.73	19 25 42.7	− 13.76	...
1252	5026	Bootis	6.0	09 01	2.28	38 42 54.7	13.61	.00
1253	5024	3 Serpentis	5.3	09 13	2.98	5 23 08.4	13.60	− .03
1254	5031	χ Bootis	5.2	09 28	2.51	29 36 37.0	13.58	+ .01
1255	5030	4 Serpentis	5.6	09 42	3.06	0 49 03.2	13.57	+ .01
1256	5036	δ Bootis	3.6	10 40	2.42	33 45 48.5	13.51	− .09
1257	5047	5 Serpentis	4.9	13 11	3.05	2 13 13.3	13.34	− .52
1258	5058	Ursæ Minoris . . .	5.1	13 15	0.66	67 48 10.3	13.34	− .39
1259*	. .	D. M. 46°, 2052 . . .	5.8	14.2	2.03	46 03	13.27	...
1260	5061	o Coronæ Borealis . .	5.7	15 11	2.48	30 03 07.6	13.21	− .06
1261	. .	D. M. 25°, 2902 . . .	5.8	15 15 56	+ 2.59	25 23 32.0	− 13.16	...
1262	5071	Draconis	5.6	16 34	1.76	52 23 28.5	13.12	.00
1263	5072	50 Bootis	5.3	17 00	2.40	33 21 51.8	13.09	+ .02
1264	5079	11 Ursæ Minoris . . .	5.2	17 12	− 0.06	72 15 34.3	13.08	+ .03
1265	5076	Bootis	5.4	18 11	+ 2.22	40 00 38.5	13.01	.00
1266	5075	η Coronæ Borealis . .	5.0	18 15	2.48	30 43 19.9	13.01	− .18
1267	5084	μ Bootis	4.3	19 57	2.26	37 47 56.0	12.89	+ .09
1268*	. .	D. M. 45°, 2284 . . .	5.7	20.1	2.02	45 42	12.88	...
1269	5085	τ^1 Serpentis	4.8	20 14	2.78	15 51 04.5	12.88	+ .08
1270	. .	Draconis	6.0	20 23	1.10	62 28 28.6	12.86	...
1271	5091	Draconis	5.8	15 20 38	+ 0.99	63 46 16.2	− 12.85	.00
1272	5094	γ Ursæ Minoris . . .	3.0	20 56	− 0.12	72 15 40.8	12.82	+ .03
1273	. .	Bootis	5.8	21 35	+ 2.36	34 45 15.2	12.78	...
1274	5097	ι Draconis	3.2	22 16	1.33	59 23 13.6	12.74	+ .04
1275*	. .	Coronæ Borealis . .	5.8	22.5	2.58	25 31	12.72	...
1276	5098	β Coronæ Borealis . .	3.7	22 53	2.48	29 31 12.8	12.70	+ .07
1277*	. .	D. M. 47°, 2227 . . .	5.4	24.9	1.93	47 38	12.56	...
1278	5122	ν Bootis (pr.)	4.8	26 37	2.15	41 14 35.8	12.44	+ .01
1279	5119	A^1 Serpentis	5.8	26 47	3.09	− 0 46 41.2	12.43	− .09
1280	5130	ν Bootis (sq.)	4.9	27 29	2.14	41 18 27.7	12.38	+ .01
1281	5131	ϑ Coronæ Borealis . .	4.2	15 28 05	+ 2.41	31 45 54.8	− 12.34	− .02
1282†	5135	δ Serpentis	3.8	29 04	2.86	10 56 27.8	12.27	+ .05
1283	5147	Draconis	5.7	29 16	0.86	64 36 42.7	12.25	+ .01
1284	5143	α Coronæ Borealis . .	2.1	29 36	2.54	27 07 10.8	12.23	− .07
1285	5146	τ^3 Serpentis	5.8	30 06	2.72	18 03 25.3	12.20	+ .04
1286	5155	μ Coronæ Borealis . .	6.0	30 51	2.20	39 24 34.1	12.15	.00
1287	5153	τ^5 Serpentis	5.8	30 58	2.76	16 31 01.8	12.14	− .01
1288	. .	Draconis	6.0	32 06	1.58	54 19 11.6	12.06	...
1289*	. .	D. M. 52°, 1886 . . .	5.8	32.7	1.68	52 28	12.02	...
1290	. .	D. M. 55°, 1766 . . .	5.8	32 52	1.54	55 01 39.1	12.01	...
1291	5168	ϕ Bootis	5.1	15 33 31	+ 2.15	40 44 42.7	− 11.96	+ .07
1292	5177	Herculis	5.7	34 26	1.92	47 11 37.3	11.90	− .13
1293	. .	Draconis	5.8	34 27	1.54	54 54 08.6	11.90	...
1294	5178	ζ Coronæ Borealis . .	4.4	34 52	2.26	37 01 32.3	11.87	− .10
1295	5191	ϑ Ursæ Minoris . . .	5.0	35 00	− 1.92	77 44 53.8	11.86	+ .01
1296	5181	Draconis	5.6	35 04	+ 1.75	50 48 56.7	11.85	.00
1297	5180	τ^6 Serpentis	5.8	35 28	2.76	16 24 46.6	11.82	+ .06
1298	5185	χ Serpentis	5.4	36 09	2.82	13 13 59.9	11.77	.00
1299	5187	ι Serpentis	4.5	36 12	2.67	20 03 29.4	11.77	− .02
1300	5189	τ^7 Serpentis	5.8	36 31	2.70	18 50 51.7	11.75	+ .09

† Double.

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1301*	. .	Ursæ Minoris . . .	5.8	15 37.4	+ 0.14	69 40	− 11.69	...
1302	5192	γ Coronæ Borealis . .	3.8	37 42	2.52	26 40 36.7	11.67	+ .08
1303	5196	α Serpentis	2.8	38 21	2.95	6 48 15.0	11.62	+ .05
1304	5210	Draconis	5.1	39 35	1.63	52 44 23.3	11.53	.00
1305	5206	A² Serpentis	5.6	39 53	3.10	− 1 25 36.8	11.51	− .05
1306	5214	λ Serpentis	4.7	40 37	2.91	7 43 49.5	11.46	− .04
1307	5216	β Serpentis	3.6	40 39	2.77	15 47 55.2	11.46	− .01
1308	5223	υ Serpentis	5.8	41 43	2.79	14 29 06.8	11.38	− .10
1309	5234	κ Serpentis	4.0	43 20	2.70	18 30 48.7	11.26	− .06
1310	5236	R Coronæ Borealis . .	var. 6–13.	43 38	2.49	28 31 34.1	11.24	.00
1311	5238	ω Serpentis	5.5	15 44 14	+ 3.02	2 33 49.4	− 11.20	− .07
1312	5244	δ Coronæ Borealis . .	4.6	44 34	2.51	26 26 12.0	11.17	− .06
1313	5248	Draconis	5.4	44 44	1.44	55 44 40.0	11.16	...
1314	5245	ε Serpentis	3.7	44 50	2.99	4 50 24.2	11.16	+ .07
1315	5249	Draconis	5.5	44 50	0.90	62 58 14.8	11.16	− .05
1316	. .	Draconis	6.0	45 13	1.15	59 56 14.0	11.13	...
1317	5252	ρ Serpentis	4.9	46 00	2.63	21 20 24.5	11.07	+ .03
1318	5259	κ Coronæ Borealis . .	4.8	46 42	2.25	36 01 39.0	11.02	− .33
1319	5285	ζ Ursæ Minoris . . .	4.5	48 23	− 2.25	78 09 46.3	10.89	− .00
1320	5271	χ Herculis	4.5	48 32	+ 2.07	42 47 16.0	10.88	+ .58
1321	5287	2 Herculis	5.2	15 50 38	+ 2.01	43 29 19.5	− 10.73	+ .06
1322	5284	γ Serpentis	3.6	50 55	2.77	16 03 16.0	10.71	−1.27
1323	5295	λ Coronæ Borealis . .	5.6	51 26	2.18	38 17 40.2	10.67	+ .09
1324	5298	4 Herculis	5.7	51 28	2.02	42 54 37.7	10.66	.00
1325	5293	φ Serpentis	5.6	51 43	2.78	14 45 32.8	10.65	− .05
1326	5302	ε Coronæ Borealis . .	4.1	52 37	2.48	27 13 35.1	10.58	− .03
1327	5310	Coronæ Borealis . .	5.9	54 32	2.22	36 59 06.2	10.44	+ .02
1328	5313	Draconis	5.0	54 56	1.41	55 05 20.5	10.41	.00
1329*	5316	Herculis	5.8	55 40	1.70	50 13 26.8	10.35	.00
1330	5315	r Herculis	5.2	55 51	2.69	18 09 04.5	10.34	+ .17
1331	5319	ρ Coronæ Borealis . .	5.5	15 56 27	+ 2.29	33 40 00.1	− 10.29	− .75
1332	5321	ι Coronæ Borealis . .	4.7	56 38	2.41	30 11 14.7	10.28	− .07
1333	5322	π Serpentis	4.5	57 08	2.58	23 08 20.8	10.25	+ .08
1334	5341	Draconis	6.0	59 02	1.52	53 15 00.4	10.10	.00
1335	5338	υ Herculis	4.6	59 04	1.86	46 22 13.8	10.10	− .07
1336	5348	ϑ Draconis	4.1	59 38	1.11	58 53 09.5	10.06	+ .32
1337	5367	κ Herculis	5.1	16 02 40	2.70	17 22 04.2	9.82	.00
1338	5385	τ Coronæ Borealis . .	4.8	04 35	2.20	36 47 48.5	9.68	+ .35
1339	5388	φ Herculis	4.1	04 59	1.87	45 15 00.4	9.65	+ .04
1340	5406	Draconis	5.6	06 00	0.14	68 07 35.3	9.57	+ .07
1341	5399	10 Herculis	5.9	16 06 31	+ 2.55	23 48 21.5	− 9.53	− .02
1342	5405	9 Herculis	5.8	07 19	2.97	5 19 45.3	9.47	− .03
1343	. .	Ursæ Minoris . . .	5.8	07 31	− 2.08	77 06 45.8	9.45	...
1344	. .	D. M. 39°, 2961 . . .	5.8	07 54	+ 2.10	39 21 54.1	9.42	...
1345	5426	16 Herculis	6.0	10 10	2.66	19 06 43.5	9.25	− .09
1346	5432	σ Coronæ Borealis . .	5.4	10 11	2.24	34 09 49.8	9.25	− .04
1347	5440	υ Coronæ Borealis . .	5.5	11 56	2.40	29 26 53.3	9.10	− .05
1348	5462	19 Ursæ Minoris . . .	5.6	14 15	− 1.79	76 10 43.2	8.93	.00
1349	5459	Draconis	5.6	15 15	+ 0.99	60 03 46.5	8.85	.00
1350	5460	Herculis	5.4	15 49	2.06	39 59 48.2	8.81	.00

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1351	5461	Herculis	6.0	16 15 50	+ 1.67	49 19 32.6	− 8.81	...
1352	5456	σ Serpentis	4.9	16 00	3.04	1 18 44.5	8.79	+ .07
1353	5463	τ Herculis	3.8	16 08	1.80	46 35 59.0	8.78	+ .03
1354	5466	γ Herculis	3.8	16 38	2.64	19 26 10.0	8.74	+ .06
1355	5473	ξ Coronæ Borealis	4.9	17 25	2.34	31 10 17.1	8.68	+ .12
1356	5479	ν Coronæ Borealis (pr.)	5.4	17 51	2.26	34 04 55.5	8.65	− .08
1357	5480	ν Coronæ Borealis (sq.)	5.8	17 58	2.27	33 58 58.8	8.65	− .02
1358	5481	21 Herculis (o)	5.8	18 20	2.92	7 13 37.0	8.60	+ .04
1359	5490	ω Herculis	4.9	19 53	2.76	14 18 40.2	8.48	− .02
1360	5511	η Ursæ Minoris	4.9	21 02	− 1.80	76 01 51.6	8.40	+ .26
1361	5496	25 Herculis	5.5	16 21 08	+ 2.13	37 40 05.8	− 8.39	.00
1362	5502	Draconis	5.4	21 48	1.30	55 28 41.6	8.33	.00
1363	5514	Draconis	5.4	22 06	− 0.16	69 23 12.3	8.31	.00
1364	5512	η Draconis	2.8	22 22	+ 0.82	61 47 10.1	8.29	+ .07
1365*	. .	Ophiuchi	5.8	22.5	3.05	0 55	8.27	...
1366	5523	g Herculis	var. 4.7–6.1	24 42	1.97	42 08 50.5	8.10	+ .09
1367	5520	λ Ophiuchi	3.9	24 52	3.02	2 14 53.2	8.09	− .05
1368	5525	β Herculis	3.0	25 04	2.58	21 45 00.5	8.07	+ .01
1369	5527	s Herculis	5.8	25 21	2.61	20 44 35.2	8.05	.00
1370	5531	n Herculis	5.6	26 42	2.95	5 46 40.0	7.94	− .04
1371	5535	34 Herculis	5.7	16 26 48	+ 1.64	49 13 21.3	− 7.93	− .07
1372	5532	h Herculis	5.1	27 00	2.81	11 44 49.2	7.92	− .05
1373	5545	A Draconis	5.0	28 13	− 0.14	69 01 39.3	7.82	+ .03
1374*	. .	Herculis	5.7	28.3	+ 1.80	45 53	7.81	...
1375	5547	12 Ophiuchi	5.5	30 03	3.09	− 2 04 00.8	7.67	− .32
1376	5552	σ Herculis	4.2	30 15	1.93	42 41 07.5	7.65	+ .04
1377	5560	Draconis	5.8	30 45	0.85	61 04 30.9	7.62	+ .04
1378	5563	D. M. 13° 3177	5.8	32 16	2.76	13 55 50.1	7.49	− .13
1379	5592	Ursæ Minoris	5.6	32 27	− 3.42	79 13 03.7	7.47	.00
1380	5568	Herculis	5.7	32 41	+ 1.75	46 51 26.0	7.45	...
1381	5574	16 Draconis	5.2	16 33 21	+ 1.41	53 08 30.3	− 7.40	+ .02
1382	5575	17 Draconis	4.9	33 24	1.41	53 09 56.8	7.40	.00
1383	5587	Herculis	6.0	35 16	2.79	12 37 43.6	7.24	− .06
1384	5596	42 Herculis	4.6	35 30	1.63	49 09 48.2	7.22	− .01
1385	5599	Draconis	5.3	35 35	1.21	56 14 59.9	7.22	.00
1386	5597	Herculis	5.8	36 02	2.49	25 05 27.4	7.19	.00
1387	5602	39 Herculis	5.9	36 45	2.43	27 08 56.1	7.12	− .02
1388	5604	ζ Herculis	3.0	36 46	2.26	31 49 16.4	7.12	+ .45
1389	5617	η Herculis	3.5	38 47	2.05	39 09 05.7	6.96	− .07
1390	5619	Herculis	5.6	39 26	2.22	34 15 35.2	6.91	− .01
1391	5621	i Herculis	5.5	16 40 04	+ 2.88	8 48 10.2	− 6.85	+ .04
1392	5628	g Draconis	5.2	40 05	0.40	64 48 59.8	6.85	− .02
1393*	. .	Herculis	6.0	41.4	1.88	43 26	6.75	...
1394	5631	l Herculis	5.4	41 52	2.05	5 27 59.6	6.70	− .06
1395	. .	D. M. 13°, 3225	5.7	42 37	2.76	13 48 13.4	6.64	...
1396	5643	Herculis	4.9	43 01	1.13	56 59 46.6	6.61	.00
1397	5647	Herculis	5.6	44 02	2.77	13 28 20.6	6.53	.00
1398	5648	k Herculis	5.7	44 30	2.91	7 27 23.2	6.49	+ .02
1399	5659	21 Ophiuchi	5.8	45 20	3.04	1 25 19.2	6.42	+ .01
1400	5667	52 Herculis	4.9	45 43	1.75	46 11 34.9	6.39	− .07

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1401	5677	51 Herculis	5.2	16 46 47	+ 2.48	24 51 32.5	− 6.30	+ .01
1402	5692	ι Ophiuchi	4.4	48 20	2.84	10 21 50.6	6.17	− .04
1403	5705	Ursæ Minoris	6.0	48 27	− 2.76	77 43 08.8	6.15	.00
1404*	. .	Herculis	5.6	49.7	+ 2.58	21 11	6.05	...
1405	5702	54 Herculis	5.0	50 06	2.63	18 37 36.3	6.02	+ .05
1406	5708	κ Ophiuchi	3.2	51 59	2.83	9 33 47.0	5.86	+ .02
1407	5740	h Draconis	5.0	55 22	0.31	65 19 04.5	5.58	+ .01
1408	5731	ε Herculis	3.9	55 42	2.29	31 06 15.5	5.55	+ .04
1409*	. .	Herculis	5.7	55.9	2.53	22 49	5.54	...
1410	5752	Draconis	6.0	57 10	1.10	56 51 57.1	5.43	+ .37
1411	5747	d Herculis	5.0	16 57 11	+ 2.21	33 44 35.8	− 5.43	+ .03
1412	. .	Herculis	5.8	57 23	2.45	25 40 32.2	5.41	...
1413	5749	Herculis	4.9	57 38	2.75	14 15 57.6	5.39	− .05
1414	5780	ε Ursæ Minoris	4.3	58 19	− 6.37	82 13 56.2	5.33	+ .00
1415	5769	Ursæ Minoris	6.0	58 40	− 1.23	73 18 31.7	5.30	.00
1416	5760	Ophiuchi	5.7	59 21	+ 3.09	− 0 43 40.0	5.25	− .14
1417*	. .	Herculis	5.8	59.3	2.61	19 46	5.25	...
1418	5765	60 Herculis	4.7	59 49	2.78	12 54 26.0	5.21	+ .02
1419*	. .	Herculis	5.8	17 01.2	2.54	22 15	5.09	...
1420	5776	Herculis	6.0	01 38	1.58	48 58 07.5	5.06	− .19
1421	5785	μ Draconis	4.8	17 02 51	+ 1.25	54 37 42.1	− 4.95	+ .03
1422	5788	c Herculis	5.3	03 47	2.12	36 05 30.6	4.88	− .02
1423	5811	Ursæ Minoris	5.7	05 27	− 1.94	75 27 46.5	4.72	.00
1424*	. .	Herculis	4.9	05.7	+ 1.95	40 56	4.71	...
1425	5802	37 Ophiuchi	5.5	06 48	2.83	10 43 55.8	4.63	− .01
1426*	. .	Draconis	5.8	07.9	1.37	52 33	4.52	...
1427	5823	ζ Draconis	3.1	08 27	0.17	65 51 45.1	4.47	+ .07
1428	5821	α Herculis	var. 3.3–3.9	09 11	2.73	14 31 41.8	4.41	+ .04
1429	5828	δ Herculis	3.1	10 06	2.46	24 58 54.0	4.33	− .15
1430*	. .	Ophiuchi	5.6	10.5	3.04	1 21	4.30	...
1431	5830	41 Ophiuchi	4.6	17 10 27	+ 3.08	− 0 18 30.4	− 4.30	− .06
1432	5834	π Herculis	3.3	10 52	2.09	36 56 43.8	4.26	+ .04
1433	5840	Draconis	5.5	11 31	0.51	63 00 39.8	4.21	− .03
1434*	. .	Herculis	5.8	12.8	2.66	17 27	4.10	...
1435	5842	u Herculis	4.9	12 54	2.21	33 13 50.3	4.09	+ .02
1436	5841	Ophiuchi	4.9	12 59	2.82	10 59 44.6	4.08	− .09
1437	5847	e Herculis	4.7	13 32	2.07	37 25 05.1	4.04	+ .08
1438*	. .	Herculis	5.5	14.1	2.35	28 57	3.99	...
1439	. .	Herculis	5.8	14 22	2.01	38 56 04.0	3.97	...
1440	5856	Herculis	5.4	15 02	2.64	18 10 53.1	3.91	− .05
1441*	. .	Herculis	5.8	17 15.3	+ 2.44	25 39	− 3.89	...
1442	5860	70 Herculis	5.5	15 58	2.47	24 37 11.1	3.83	.00
1443	5863	w Herculis	5.3	16 10	2.24	32 37 25.6	3.82	− 1.00
1444	5871	71 Herculis	5.3	16 58	1.69	46 21 32.4	3.74	+ .02
1445	5874	Herculis	5.5	17 47	1.97	40 05 37.4	3.67	.00
1446	5883	73 Herculis	5.6	19 06	2.52	23 04 22.5	3.56	− .03
1447*	. .	Ophiuchi	5.4	19.1	2.69	16 25	3.56	...
1448*	. .	Draconis	5.8	19.2	1.29	53 32	3.55	...
1449	5886	ρ Herculis	4.1	19 32	2.07	37 15 28.7	3.52	+ .02
1450	5893	σ Ophiuchi	4.2	20 34	2.98	4 14 45.9	3.43	+ .02

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1451	5900	Herculis	5.6	17 21 38	+ 2.59	20 10 59.3	− 3.34	− .13
1452	5903	Ophiuchi	5.3	22 43	3.06	0 25 41.4	3.25	− .12
1453	5911	x Herculis	5.7	23 33	1.59	48 21 41.0	3.17	− .03
1454	5917	Draconis	5.2	24 08	0.77	60 08 58.0	3.13	...
1455*	5910	Ophiuchi	5.3	24.2	3.09	− 0 57	3.12	...
1456	5918	Draconis	6.0	24 17	0.89	58 45 10.2	3.11	+ .04
1457	5919	Ophiuchi	5.6	25 20	3.00	2 48 58.0	3.02	− .06
1458	5922	λ Herculis	4.6	25 53	2.42	26 12 09.6	2.97	+ .07
1459	5927	Herculis	5.7	26 23	2.28	31 14 55.3	2.93	+ .03
1460	5931	78 Herculis	5.6	27 07	2.36	28 29 44.4	2.87	+ .06
1461	5937	β Draconis	2.9	17 27 43	+ 1.35	52 23 26.9	− 2.82	.00
1462*	. .	Herculis	5.3	28.1	2.61	19 21	2.78	...
1463*	. .	Ophiuchi	5.1	28.3	2.68	16 26	2.77	...
1464	5944	Herculis	5.6	29 19	1.91	41 19 46.3	2.68	.00
1465	5941	α Ophiuchi	2.0	29 22	2.78	12 38 56.1	2.68	− .20
1466	5950	ν Draconis (pr.) . . .	5.0	29 49	1.18	55 15 59.1	2.64	+ .03
1467	5951	ν Draconis (sq.) . . .	5.0	29 54	1.18	55 15 17.1	2.63	+ .01
1468*	. .	Herculis	5.8	30.9	2.56	21 05	2.54	...
1469	5962	Herculis	5.8	32 03	2.28	30 51 37.9	2.44	+ .01
1470	5972	f Draconis	5.4	32 27	− 0.25	68 12 39.7	2.40	+ .11
1471	5967	79 Herculis	5.8	17 32 35	+ 2.47	24 22 57.1	− 2.38	+ .01
1472	5975	y Herculis	5.3	33 29	1.56	48 39 21.2	2.31	+ .03
1473	5978	26 Draconis	5.6	33 45	0.61	61 58 03.4	2.29	− .36
1474	. .	Ophiuchi	6.0	35.7	2.71	15 14 30.4	2.12	...
1475	5990	ι Herculis	3.8	36 05	1.70	46 04 15.1	2.09	+ .01
1476	5991	Ophiuchi	5.4	36 36	2.69	16 00 31.5	2.04	+ .07
1477	5999	83 Herculis	6.0	37 33	2.46	24 37 34.3	1.96	+ .05
1478	5996	β Ophiuchi	3.1	37 33	2.96	4 37 08.0	1.96	+ .17
1479	6006	ω Draconis	4.8	37 39	− 0.36	68 48 46.2	1.95	+ .29
1480*	. .	D. M. 14°, 3321 . . .	5.8	37.9	+ 2.73	14 21	1.93	...
1481*	. .	Draconis	5.8	17 38.6	+ 1.38	51 53	− 1.87	...
1482*	. .	Ophiuchi	5.8	38.8	2.73	14 28	1.85	...
1483*	. .	D. M. 72°, 800 . . .	5.8	39.4	− 1.16	72 31	1.80	...
1484*	. .	Draconis	5.5	41.6	+ 1.25	53 50	1.61	...
1485	6021	μ Herculis	3.6	41 46	2.34	27 47 31.4	1.59	− .74
1486*	. .	Herculis	5.4	41.8	2.65	17 47	1.59	...
1487*	. .	Herculis	6.2	41.9	2.00	38 56	1.58	...
1488	6020	γ Ophiuchi	3.7	41 52	3.00	2 45 13.7	1.58	− .07
1489*	. .	Herculis	6.1	42.0	1.98	39 22	1.57	...
1490*	. .	Herculis	5.6	43.3	2.57	20 36	1.46	...
1491	6030	Herculis	6.0	17 43 36	+ 2.60	19 17 40.3	− 1.43	− .01
1492	6033	87 Herculis	5.4	43 57	2.43	25 39 54.9	1.40	+ .21
1493	6047	ψ Draconis (pr.) . . .	4.5	44 04	− 1.08	72 12 26.1	1.40	− .26
1494*	. .	Herculis	6.0	45.7	+ 2.32	29 22	1.25	...
1495	6052	30 Draconis	4.9	46 12	1.43	50 48 36.0	1.21	+ .19
1496*	. .	Ophiuchi	5.8	46.5	3.04	1 21	1.18	...
1497*	. .	Ophiuchi	6.0	47.4	2.93	6 07	1.10	...
1498	6068	f Herculis	5.0	49 24	1.95	40 01 51.7	0.93	+ .04
1499	6069	Ophiuchi	5.7	50 12	3.06	0 41 23.7	0.86	− .03
1500	6073	89 Herculis	5.6	50 35	2.42	26 04 13.3	0.82	+ .02

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE

No.	B.A.C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1501*	. .	Herculis	5.3	17 50.8	+ 2.52	22 28	− 0.81	...
1502	6079	ξ Draconis	3.8	51 27	1.04	56 53 30.6	0.74	+ .06
1503	6082	ϑ Herculis	3.8	52 08	2.06	37 16 03.7	0.69	+ .05
1504	6084	ξ Herculis	4.0	53 06	2.33	29 15 41.7	0.60	− .02
1505	6091	γ Draconis	2.3	53 49	1.39	51 30 12.4	0.54	− .04
1506	6087	ν Herculis	4.6	53 55	2.30	30 12 00.4	0.53	.00
1507	6089	66 Ophiuchi	5.1	54 19	2.97	4 22 38.9	0.50	+ .01
1508*	. .	Herculis	5.8	54.5	2.09	36 17	0.48	...
1509	6092	67 Ophiuchi	4.0	54 38	3.00	2 56 18.9	0.47	− .03
1510	6094	93 Herculis	5.0	54 43	2.67	16 45 33.0	0.46	+ .03
1511	6114	35 Draconis	5.1	17 54 49	− 2.69	76 58 38.7	− 0.45	+ .24
1512	6101	68 Ophiuchi	4.5	55 40	+ 3.04	1 18 35.2	0.38	+ .02
1513*	. .	Herculis	5.4	56.2	2.20	33 13	0.33	...
1514	6106	95 Herculis	4.5	56 25	2.54	21 35 52.5	0.32	+ .06
1515	6109	Herculis	5.5	56 31	1.72	45 30 27.2	0.31	− .06
1516*	. .	D. M. 33°, 3009 . . .	5.8	57.2	2.19	33 30	0.25	...
1517	6110	96 Herculis	5.0	57 15	2.56	20 50 04.3	0.24	+ .01
1518	6122	34 Draconis	5.8	57 16	− 1.05	72 00 54.4	0.24	− .28
1519	6123	70 Ophiuchi	4.2	59 23	+ 3.03	2 31 45.7	− 0.05	−1.09
1520	6134	98 Herculis	5.3	18 00 59	2.53	22 12 32.8	+ 0.09	+ .04
1521*	. .	Herculis	5.8	18 01.4	+ 2.23	32 14	+ 0.12	...
1522	6142	71 Ophiuchi	4.9	01 34	2.87	8 43 10.9	0.14	+ .04
1523	6143	72 Ophiuchi	3.7	01 40	2.84	9 32 52.5	0.15	+ .06
1524	6147	b Herculis	4.9	02 28	2.28	30 32 44.5	0.21	+ .08
1525	6150	o Herculis	3.8	02 52	2.34	28 44 50.9	0.25	+ .02
1526	6151	100 Herculis	5.5	02 59	2.42	26 04 52.0	0.26	+ .07
1527	6157	102 Herculis	4.3	03 38	2.56	20 47 49.1	0.32	− .01
1528	6159	101 Herculis	5.1	03 42	2.58	20 01 38.9	0.32	− .04
1529*	. .	Herculis	5.7	03.9	2.09	36 23	0.34	...
1530	6162	Herculis	4.8	03 52	1.80	43 26 53.0	0.34	.00
1531*	. .	D. M. 3°, 3620 . . .	5.8	18 04.7	+ 3.00	3 18	+ 0.41	...
1532*	. .	Herculis	6.0	04.8	2.68	16 27	0.42	...
1533*	. .	Herculis	5.8	5.8	2.08	36 26	0.51	...
1534	6178	104 Herculis (A)	5.0	07 23	2.26	31 22 36.6	0.65	+ .09
1535	6185	Draconis	5.8	08 03	1.21	54 15 03.2	0.70	+ .25
1536	. .	Lyræ	5.9	08 54	1.90	41 07 03.5	0.77	...
1537	6193	Lyræ	5.8	09 05	2.00	38 44 26.8	0.80	+0.79
1538	6281	δ Ursæ Minoris . . .	4.4	11 03	−19.43	86 36 32.8	0.97	+ .04
1539	6203	Lyræ	5.5	11 55	+ 1.86	42 07 08.7	1.04	.00
1540	6224	36 Draconis	5.0	13 12	0.34	64 21 23.2	1.16	+ .01
1541	6218	Lyræ	5.9	18 13 19	+ 1.92	40 53 22.7	+ 1.16	.00
1542	6213	Ophiuchi	5.7	13 22	2.90	7 12 43.0	1.17	.00
1543	6223	105 Herculis	5.5	14 14	2.47	24 23 50.0	1.24	.00
1544	6227	74 Ophiuchi	5.2	14 53	3.00	3 19 28.0	1.30	+ .01
1545	6231	106 Herculis	5.4	15 13	2.54	21 54 42.4	1.33	− .01
1546	6320	24 Ursæ Minoris . . .	5.8	15 15	−22.25	86 59 17.8	1.33	+ .01
1547	6235	κ Lyræ	4.6	15 40	+ 2.10	36 00 40.5	1.37	+ .03
1548	6243	37 Draconis	6.1	15 59	− 0.35	68 42 43.5	1.40	− .06
1549	6237	108 Herculis	5.4	16 20	+ 2.30	29 48 10.1	1.43	+ .04
1550	6238	t Herculis	4.7	16 20	2.34	28 48 50.6	1.43	+ .06

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1551*	. .	Ophiuchi	5.8	18 17 . .	+ 2.79	11 59	+ 1.49	. . .
1552	6245	Herculis	5.4	17 31	2.64	17 46 01.8	1.53	. . .
1553	6255	Draconis	4.8	18 28	1.53	49 03 40.3	1.62	.00
1554	6251	109 Herculis	4.2	18 35	2.56	21 42 59.7	1.63	— .24
1555*	. .	Ophiuchi	5.7	19.9	2.89	7 58	1.74	. . .
1556	6268	μ Lyræ	4.9	20 17	1.97	39 26 34.0	1.78	.00
1557	6269	d Serpentis	5.6	21 04	3.07	0 07 34.5	1.84	.00
1558	6289	b Draconis	4.9	22 09	0.87	58 43 53.8	1.93	+ .04
1559	6297	φ Draconis	4.3	22 29	— 0.85	71 16 24.7	1.96	+ .01
1560	6302	χ Draconis	3.7	23 13	— 1.07	72 40 48.7	2.02	— .38
1561	6300	Herculis	5.8	18 24 37	+ 2.50	23 47 15.6	+ 2.15	.00
1562	6316	42 Draconis	5.1	25 38	0.17	65 29 19.8	2.24	— .06
1563*	. .	Herculis	5.4	25.7	2.67	16 51	2.24	. . .
1564	6322	Herculis	5.8	27 47	2.50	23 31 42.5	2.43	.00
1565*	. .	Lyræ	5.4	28.3	2.29	30 28	2.47	. . .
1566	6348	d Draconis	4.9	30 30	1.04	56 57 14.9	2.66	— .02
1567	6341	Herculis	5.8	30 31	2.50	23 30 32.4	2.66	— .05
1568*	. .	Ophiuchi	5.2	30.7	2.86	9 02	2.68	. . .
1569*	. .	Ophiuchi	5.5	30.8	2.92	6 34	2.69	. . .
1570	6350	Draconis	5.3	31 13	1.36	52 15 31.5	2.72	.00
1571*	. .	c Serpentis	5.6	18 31.4	+ 3.08	— 0 25	+ 2.74	. . .
1572*	. .	Lyræ	5.7	32.2	2.20	33 22	2.81	. . .
1573	6355	α Lyræ	0.1	32 53	2.03	38 40 22.3	2.87	+ .28
1574	. .	Lyræ	6.0	33 05	1.83	43 07 15.2	2.87	. . .
1575	. .	Draconis	5.8	35 51	0.19	65 22 50.5	3.12	. . .
1576	. .	Draconis	5.6	36 29	0.54	62 25 01.0	3.18	. . .
1577	6372	Draconis	5.6	37 08	1.39	52 05 01.6	3.23	+ .03
1578	6379	4 Aquilæ	5.0	38 47	3.03	1 56 22.5	3.38	+ .02
1579*	. .	Lyræ	5.6	39.4	2.25	31 49	3.43	. . .
1580	6395	c Draconis	5.1	40 18	1.16	55 25 05.0	3.51	.00
1581	6390	ε Lyræ (bor.)	4.6	18 40 22	+ 1.99	39 32 43.7	+ 3.51	+ .07
1582	6391	ε Lyræ (aus.)	4.6	40 22	1.99	39 29 17.8	3.51	+ .08
1583	6387	110 Herculis	4.2	40 30	2.59	20 25 56.9	3.52	— .35
1584	6392	ζ Lyræ (pr.).	4.5	40 38	2.06	37 28 50.2	3.53	+ .02
1585	6394	ζ Lyræ (sq.).	5.5	40 40	2.06	37 28 11.6	3.54	+ .02
1586	. .	D. M. 53°, 2126 . . .	5.8	40 56	1.28	53 44 59.2	3.56	. . .
1587*	. .	Lyræ	4.8	41.2	2.42	26 32	3.58	. . .
1588	6397	111 Herculis	4.1	41 43	2.65	18 02 56.9	3.63	— .12
1589	6404	Lyræ	5.9	42 23	1.92	41 18 48.6	3.69	.00
1590*	. .	Draconis	6.0	42.5	1.21	54 46	3.70	. . .
1591	6410	Draconis	6.0	18 42 52	+ 0.71	60 55 15.2	+ 3.73	— .03
1592*	. .	Lyræ	5.8	43.5	2.26	31 38	3.78	. . .
1593*	. .	D. M. 24°, 3545 . . .	5.8	44.3	2.46	24 54	3.85	. . .
1594	6428	Draconis	5.9	45 06	1.58	48 37 49.4	3.92	.00
1595	6427	ν Lyræ	5.4	45 24	2.24	32 24 49.3	3.95	+ .01
1596	6429	β Lyræ	var. 3.6–4.4	45 39	2.21	33 13 27.4	3.96	— .01
1597*	. .	Aquilæ	5.7	46.5	2.75	13 50	4.04	. . .
1598	6438	112 Herculis	5.2	47 09	2.56	21 16 55.5	4.10	+ .07
1599	6469	Draconis	5.5	48 45	— 1.46	73 56 46.0	4.23	+ .13
1600	6452	Draconis	5.6	48 54	+ 1.35	52 49 11.8	4.25	.00

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s	° ′ ″	″	″
1601	6463	o Draconis	4.5	18 49 26	+ 0.89	59 14 30.6	+ 4.29	+ .01
1602	6451	62 Serpentis	5.7	49 36	2.93	6 27 59.8	4.31	− .06
1603	6453	113 Herculis	4.6	49 41	2.54	22 29 38.6	4.31	+ .01
1604	6478	50 Draconis	5.6	50 14	− 1.91	75 17 28.6	4.36	+ .06
1605	6470	Draconis	5.1	50 15	+ 1.48	50 33 34.5	4.36	.00
1606	6460	ϑ Serpentis (pr.)	4.4	50 15	2.98	4 02 56.2	4.36	+ .08
1607	6462	ϑ Serpentis (sq.)	4.7	50 16	2.98	4 02 52.4	4.37	+ .12
1608	6466	δ Lyræ	4.4	50 19	2.10	36 44 50.1	4.37	+ .04
1609*	. .	Herculis	5.7	50.8	2.65	17 58	4.41	...
1610	6473	Lyræ	5.4	51 01	1.92	41 26 58.2	4.43	.00
1611	6471	64 Serpentis	5.7	18 51 15	+ 3.02	2 22 46.4	+ 4.45	+ .01
1612	6476	Draconis	5.6	51 37	1.59	48 42 35.9	4.48	− .12
1613	6475	R Lyræ	var. 4.3–4.6	51 41	1.82	43 47 17.4	4.49	.00
1614*	. .	Aquilæ	5.5	52.9	2.67	17 12	4.59	...
1615*	. .	D. M. 19°. 3858	5.6	53.5	2.61	19 38	4.64	...
1616	6483	11 Aquilæ	5.1	53 34	2.76	13 27 51.0	4.65	− .05
1617	6487	ε Aquilæ	4.1	54 10	2.72	14 54 22.6	4.69	− .10
1618	6491	γ Lyræ	3.2	54 27	2.25	32 31 34.0	4.72	+ .02
1619	6496	48 Draconis	5.7	54 43	1.02	57 39 21.9	4.74	− .07
1620*	. .	Lyræ	5.7	54.9	2.44	26 04	4.76	...
1621	6497	λ Lyræ	5.6	18 55 29	+ 2.26	31 58 42.9	+ 4.81	+ .01
1622	6510	υ Draconis	5.1	55 52	− 0.71	71 08 11.6	4.84	+ .05
1623*	. .	Draconis	5.6	56.0	+ 0.28	65 07	4.85	...
1624*	. .	D. M. 20°, 4022	5.8	56.2	2.58	20 40	4.87	...
1625*	. .	Draconis	4.9	57.2	1.51	50 22	4.95	...
1626*	. .	Aquilæ	5.8	57.5	3.04	1 38	4.98	...
1627*	. .	D. M. 19°, 3888	5.8	57.7	2.61	19 29	5.00	...
1628	6520	16 Lyræ	4.9	58 03	1.71	46 45 56.3	5.02	− .06
1629	6522	49 Draconis	5.6	58 21	1.19	55 29 10.3	5.05	− .06
1630	6528	ζ Aquilæ	3.0	59 54	2.75	13 41 11.5	5.18	− .09
1631	6534	Lyræ	5.8	19 00 23	+ 2.28	31 33 58.4	+ 5.22	.00
1632	6543	18 Aquilæ	5.0	01 20	2.83	10 53 15.9	5.30	− .02
1633	6542	Vulpeculæ	5.5	01 38	2.50	24 03 59.4	5.33	+ .22
1634*	. .	Aquilæ	5.3	01.6	2.69	16 41	5.33	...
1635	6547	Lyræ	5.5	01 52	2.39	28 26 25.1	5.35	− .05
1636	6551	51 Draconis	5.6	02 13	1.35	53 12 44.7	5.37	.00
1637	6553	17 Lyræ	5.5	02 53	2.27	32 18 48.2	5.43	+ .06
1638	6556	ι Lyræ	5.1	03 01	2.14	35 54 46.8	5.44	+ .04
1639	6552	19 Aquilæ	5.2	03 07	+ 2.94	5 53 09.3	5.45	− .04
1640*	. .	D. M. 82°, 572	5.8	06.6	− 6.28	82 12	5.74	...
1641	6571	19 Lyræ	5.8	19 07 10	+ 2.30	31 05 03.4	+ 5.79	+ .06
1642	6574	Vulpeculæ	5.8	07 28	2.57	21 21 12.2	5.82	.00
1643	6572	21 Aquilæ	5.3	07 40	3.02	2 05 29.7	5.84	+ .06
1644*	. .	Aquilæ	5.8	07.8	2.95	5 18	5.85	...
1645	6583	53 Draconis	5.4	09 24	1.13	56 39 18.9	5.98	+ .05
1646	6581	η Lyræ	4.2	09 40	2.04	38 56 26.8	6.00	+ .05
1647*	. .	D. M. 19°, 3956	5.8	09.8	2.61	20 01	6.01	...
1648	6582	1 Sagittæ	5.8	10 07	2.58	21 01 24.4	6.04	+ .04
1649	6585	22 Aquilæ	5.6	10 35	2.97	4 37 28.2	6.08	− .02
1650*	. .	Lyræ	6.0	10.8	2.33	30 19	6.10	...

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1651*	. .	Aquilæ	5.6	19 11 ..	+ 2.75	14 20	+ 6.11	...
1652	6589	1 Vulpeculæ	4.7	11 04	2.58	21 10 47.8	6.12	+ .06
1653	6601	54 Draconis	5.2	11 47	1.08	57 29 53.9	6.18	− .07
1654	6595	ω Aquilæ	5.3	12 11	2.81	11 22 49.1	6.21	+ .02
1655	6599	ϑ Lyræ	4.0	12 12	2.08	37 55 14.9	6.21	.00
1656	6597	23 Aquilæ	5.1	12 26	3.05	0 52 04.8	6.23	− .04
1657	6612	δ Draconis	3.0	12 31	0.03	67 27 01.0	6.24	+ 07
1658	. .	D. M. 9°, 4057	5.8	13 09	2.86	9 24 07.8	6.30	...
1659	6625	59 Draconis	5.5	13 33	− 2.15	76 21 34.1	6.33	− .12
1660	6615	A Aquilæ	5.5	14 03	+ 2.80	12 09 16.8	6.37	+ .07
1661	6623	κ Cygni	4.2	19 14 20	+ 1.38	53 08 51.2	+ 6.39	+ .09
1662	6618	d Aquilæ	5.3	14 24	3.10	− 1 06 50.7	6.40	− .01
1663*	. .	Aquilæ	5.1	16.2	3.08	− 0 30	6.55	...
1664	6650	τ Draconis	4.5	17 51	− 1.11	73 07 55.8	6.68	+ .10
1665	6637	3 Vulpeculæ	5.4	17 56	+ 2.46	26 02 00.1	6.69	+ .01
1666	6640	Draconis (pr.)	5.9	18 04	1.10	57 25 05.3	6.70	.00
1667	6642	2 Sagittæ	5.8	18 59	2.69	16 42 19.8	6.78	+ .04
1668	6644	b Aquilæ	5.2	19 15	2.86	11 41 20.7	6.79	+ .69
1669	6648	2 Cygni	5.2	19 24	2 37	29 23 16.3	6.81	+ .05
1670	6646	δ Aquilæ	3.3	19 27	3.02	2 52 36.6	6.82	+ .10
1671	6662	π Draconis	4.8	19 20 03	+ 0.32	65 29 00.2	+ 6.86	+ .03
1672	6656	Lyræ	5.6	20 09	1.89	43 09 18.7	6.86	.00
1673	6654	4 Vulpeculæ	4.9	20 13	2.63	19 33 53.9	6.87	− .03
1674	6653	ν Aquilæ	4.9	20 23	3.07	0 06 01.2	6.89	− .02
1675*	. .	Aquilæ	5.8	20.8	2.79	12 48	6.91	...
1676	6667	4 Cygni	5.0	21 50	2.16	36 04 40.9	7.01	+ .05
1677*	. .	Aquilæ	5.8	22 ..	2.76	14 02	7.02	...
1678	6674	6 Vulpeculæ	4.3	23 43	2.49	24 25 22.9	7.16	− .09
1679*	. .	Aquilæ	5.8	23.9	2.75	14 21	7.18	...
1680	6690	β Cygni	3.1	25 53	2.42	27 42 31.6	7.34	.00
1681	6697	ι Cygni	4.2	19 26 41	+ 1.51	51 28 28.0	+ 7.41	+ .13
1682	6698	8 Cygni	4.6	27 19	2.23	34 11 55.0	7.45	+ .04
1683	. .	Cygni	5.8	28 09	1.59	50 03 00.0	7.53	...
1684	6701	μ Aquilæ	4.7	28 14	2.93	7 07 32.1	7.53	− .14
1685	6709	9 Vulpeculæ	5.3	29 19	2.63	19 30 45.6	7.54	+ .03
1686*	. .	D. M. 15°, 3872	5.8	30 ..	2.73	15 21	7.67	...
1687	6714	9 Cygni	5.6	30 05	2.39	29 11 57.7	7.68	− .05
1688*	. .	Cephei	5.8	30.2	− 7.34	83 14	7.69	...
1689	6715	ι Aquilæ	4.3	30 31	+ 3.11	− 1 33 04.5	7.71	+ .01
1690	6718	Cygni	5.2	30 46	1.95	42 09 01.8	7.74	.00
1691*	6723	Cygni	5.8	19 31 14	+ 1.57	50 58 50.2	+ 7.77	− .10
1692	6722	11 Cygni	5.8	31 30	2.16	36 40 47.0	7.80	+ .04
1693	6724	ε Sagittæ	5.5	31 51	2.72	16 11 40.8	7.83	+ .06
1694	6735	σ Draconis	4.9	32 35	− 0.11	69 27 23.9	7.88	−1.79
1695	6731	Cygni	5.0	32 55	+ 1.87	44 25 51.9	7.91	.00
1696	6734	ϑ Cygni	4.5	33 13	1.61	49 56 35.7	7.93	+ .15
1697	6729	σ Aquilæ	4.9	33 16	2.96	5 07 32.3	7.94	+ .01
1698	6736	45 Aquilæ	5.8	34 32	3.10	− 0 53 53.2	8.03	+ .02
1699	6740	φ Cygni	5.1	34 38	2.37	29 52 40.0	8.04	+ .06
1700	6739	α Sagittæ	4.4	34 44	2.68	17 44 22.1	8.05	+ .03

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1701*	. .	Aquilæ	5.7	19 35.5	+ 2.78	13 33	+ 8.12	...
1702	6745	14 Cygni	5.2	35 32	1.95	42 32 31.4	8.12	+ .07
1703	6744	β Sagittæ	4.4	35 40	2.70	17 11 56.8	8.13	+ .02
1704	6748	Cygni	5.5	35 59	1.35	54 41 30.3	8.16	.00
1705	6749	χ Aquilæ	5.5	36 55	2.82	11 32 44.2	8.23	+ .07
1706	6754	Cygni	5.0	37 07	1.84	45 14 26.9	8.23	.00
1707*	. .	Cygni	5.8	38.1	2.31	32 09	8.32	...
1708	6758	10 Vulpeculæ	5.7	38 44	2.50	25 29 07.9	8.37	— .01
1709	6759	ψ Aquilæ	6.0	38 59	2.80	13 00 57.3	8.40	— .01
1710	6769	D. M. 41°, 3469	5.4	39 45	2.00	41 29 08.5	8.46	.01
1711	6767	υ Aquilæ	5.9	19 39 50	+ 2.92	7 19 24.5	+ 8.46	+ .03
1712	6771	15 Cygni	5.2	39 57	2.16	37 03 55.3	8.47	+ .08
1713	6772	γ Aquilæ	3.1	40 33	2.85	10 19 19.1	8.52	+ .00
1714	6779	δ Cygni	2.9	41 13	1.88	44 50 17.9	8.57	.00
1715	6784	17 Cygni	5.2	41 52	2.27	33 26 57.5	8.62	— .44
1716	6783	δ Sagittæ	4.0	42 02	2.68	18 14 22.4	8.63	+ .05
1717	6789	π Aquilæ	5.7	43 03	2.83	11 31 06.5	8.71	+ .02
1718	6794	ζ Sagittæ	5.1	43 39	2.67	18 50 32.7	8.76	+ .07
1719	6799	Cygni	5.9	43 56	1.75	47 36 42.1	8.78	.00
1720	6802	α Aquilæ	0.9	44 56	2.93	8 33 09.0	8.86	+ .38
1721	6805	ο Aquilæ	5.4	19 45 17	+ 2.88	10 06 58.1	+ 8.89	— .16
1722	6810	12 Vulpeculæ	5.3	45 54	2.59	22 18 22.9	8.94	+ .05
1723*	. .	χ Cygni	var. 4–13.	46 ..	2.31	32 37	8.95	...
1724	6813	19 Cygni	5.6	46 19	2.12	38 24 52.1	8.97	+ .12
1725	6811	η Aquilæ	var. 3.6–4.6	46 22	3.06	0 41 54.8	8.97	— .04
1726	6817	Cygni	5.6	46 30	2.06	40 17 42.9	8.99	.00
1727*	. .	Vulpeculæ	5.4	47 ..	2.53	24 41	9.03	...
1728	6824	20 Cygni (d)	5.2	47 37	1.50	52 41 02.6	9.07	— .05
1729*	. .	Cygni	5.6	48.4	1.81	46 43	9.14	...
1730	6827	13 Vulpeculæ	4.7	48 22	2.55	23 46 03.3	9.14	+ .08
1731	6825	ξ Aquilæ	5.1	19 48 26	+ 2.91	8 09 07.7	+ 9.14	— .09
1732	6836	ε Draconis	3.8	48 34	— 0.18	69 57 43.0	9.15	— .00
1733*	6830	Cygni	5.8	48 35	+ 1.77	47 37 21.2	9.15	+ .00
1734	6826	58 Aquilæ	5.6	48 36	3.07	0 02 21.2	9.15	— .10
1735	6833	β Aquilæ	4.0	49 25	2.95	6 06 29.2	9.21	— .47
1736	6835	Vulpeculæ	5.7	49 26	2.55	24 00 21.2	9.21	— .01
1737*	. .	Cygni	5.8	50.4	2.19	36 41	9.29	...
1738	6838	φ Aquilæ	5.3	50 33	2.85	11 06 23.0	9.31	+ .05
1739	6839	10 Sagittæ	5.3	50 34	2.73	16 19 06.5	9.31	+ .07
1740	6847	23 Cygni	5.3	50 50	1.24	57 12 33.4	9.32	.00
1741	6852	Cygni	5.7	19 51 26	+ 1.07	59 23 28.4	+ 9.37	.00
1742	6849	22 Cygni	5.3	51 34	2.14	38 10 07.2	9.38	.00
1743	6851	η Cygni	4.4	51 48	2.25	34 45 54.6	9.40	— .04
1744	6853	11 Sagittæ	5.6	52 19	2.72	16 28 02.4	9.44	+ .11
1745	6856	ψ Cygni	5.3	52 32	1.56	52 07 17.1	9.45	+ .02
1746	6857	Cygni	5.4	53 04	2.08	40 02 46.3	9.50	.00
1747	6858	γ Sagittæ	3.8	53 25	2.67	19 10 02.8	9.52	+ .08
1748	6867	Cygni	5.2	53 39	1.16	58 31 32.8	9.54	— .02
1749*	. .	Cygni	5.7	53.9	2.38	30 39	9.56	...
1750	6866	14 Vulpeculæ	5.7	54 02	2.58	22 46 31.0	9.57	— .02

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1751	6868	13 Sagittæ	5.6	19 54 38	+ 2.71	17 11 23.0	+ 9.61	+ .06
1752	6875	25 Cygni	5.5	55 31	2.16	36 42 52.9	9.68	+ .08
1753	6876	Cygni	5.7	55 34	1.88	45 26 44.3	9.69	.00
1754	6879	15 Vulpeculæ	4.9	56 09	2.47	27 25 24.3	9.73	+ .08
1755	6883	16 Vulpeculæ	5.4	56 56	2.55	24 36 10.9	9.79	+ .09
1756	6895	e Cygni	5.0	57 58	1.70	49 46 16.9	9.87	− .01
1757	6890	14 Sagittæ	5.1	58 01	2.75	15 41 43.8	9.87	+ .04
1758	6893	τ Aquilæ	5.8	58 17	2.93	6 56 25.3	9.90	+ .01
1759*	. .	Cygni	5.8	58.7	2.41	29 35	9.93	...
1760	6897	15 Sagittæ	5.5	58 43	2.69	16 44 46.7	9.93	− .36
1761	6901	η Sagittæ	5.3	19 59 50	+ 2.66	19 38 53.7	+ 10.01	+ .10
1762*	. .	Cygni	5.8	59.9	2.35	31 53	10.02	...
1763*	. .	D. M. 15°, 4040	5.8	59.9	2.76	15 10	10.02	...
1764	6905	e Draconis	5.1	20 00 12	0.65	64 29 05.8	10.04	− .02
1765	6912	17 Vulpeculæ	5.1	01 44	2.58	23 16 10.4	10.16	.00
1766	6915	b Cygni	5.6	01 54	2.23	35 38 34.0	10.17	− .41
1767	6926	ρ Draconis	4.8	02 16	0.29	67 31 52.4	10.20	+ .04
1768*	. .	Aquilæ	5.8	02.9	2.86	10 22	10.24	...
1769	6936	69 Draconis	6.1	02 57	− 1.59	76 08 45.1	10.25	− .08
1770	6928	Cygni	5.7	03 03	+ 1.56	52 48 37.8	10.25	.00
1771*	. .	Cygni	6.0	20 03.1	+ 2.30	34 04	+ 10.25	...
1772	6932	66 Draconis	5.3	03 38	0.96	61 38 50.0	10.30	+ .05
1773	6937	b² Cygni	5.3	04 58	2.22	36 29 16.0	10.40	+ .11
1774	6934	ϑ Aquilæ	3.2	05 07	3.10	− 1 10 35.0	10.41	.00
1775	6940	18 Vulpeculæ	5.5	05 33	2.50	26 32 57.5	10.44	+ .04
1776*	. .	D. M. 21°, 4088	5.8	06.1	2.62	21 31	10.47	...
1777	6943	19 Vulpeculæ	5.7	06 47	2.51	26 27 09.3	10.54	+ .05
1778	6952	ρ Aquilæ	4.9	08 43	2.78	14 50 00.3	10.67	+ .08
1779	6957	21 Vulpeculæ	5.8	09 19	2.47	28 19 54.3	10.72	− .08
1780	6962	o Cygni (pr.)	5.0	09 32	1.89	46 27 11.7	10.74	+ .01
1781	6970	68 Draconis	5.6	20 09 37	+ 0.99	61 42 54.7	+ 10.74	+ .06
1782	6965	o¹ Cygni (sq.)	3.8	09 51	1.89	46 22 42.0	10.76	+ .04
1783	6967	b³ Cygni	5.1	10 02	2.45	36 26 22.8	10.78	+ .12
1784	6966	Vulpeculæ	5.0	10 11	2.54	25 13 35.0	10.79	...
1785	6968	22 Vulpeculæ	5.4	10 19	2.59	23 08 35.9	10.80	+ .02
1786	6976	33 Cygni	4.5	10 36	1.40	56 12 01.8	10.82	+ .04
1787	6973	23 Vulpeculæ	4.8	10 48	2.48	27 26 49.4	10.83	+ .01
1788	6975	18 Sagittæ	5.9	11 03	2.64	21 13 54.6	10.85	.00
1789	6980	D. M. 60°, 2099	5.8	11 16	1.13	60 16 24.2	10.87	+ .01
1790	6979	24 Vulpeculæ	5.6	11 39	2.57	24 18 08.2	10.89	+ .02
1791	6983	o² Cygni	3.9	20 11 46	+ 1.85	47 20 46.8	+ 10.90	+ .03
1792	6986	Cygni	5.1	12 39	2.15	39 59 40.0	10.96	.00
1793	7005	κ Cephei (1st *)	4.6	12 54	− 1.89	77 20 56.1	10.99	− .00
1794	6990	P Cygni	var. 3–6	13 22	+ 2.21	37 39 38.5	11.02	+ .03
1795*	. .	Delphini	5.6	13.9	2.82	12 52	11.06	...
1796	6998	35 Cygni	5.3	14 03	2.31	34 36 30.6	11.06	+ .02
1797	. .	Cygni	5.6	15 27	1.49	55 01 20.0	11.18	...
1798	7014	115 Aquilæ	5.4	17 14	2.98	4 57 39.9	11.30	...
1799*	. .	Delphini	5.7	17.3	2.79	14 09	11.31	...
1800	7024	71 Draconis	5.6	17 36	1.01	61 52 35.3	11.33	+ .02

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1801	7022	γ Cygni	2.4	20 17 55	+ 2.15	39 52 24.6	+ 11.35	+ .02
1802*	. .	Cygni	5.5	18 10	1.95	45 24 35.6	11.37	...
1803	7027	Cygni	5.6	18 30	2.13	40 38 36.1	11.39	.00
1804	7029	39 Cygni	4.9	19 04	2.40	31 48 13.7	11.43	+ .05
1805*	. .	Cygni	5.6	19.3	2.24	37 05	11.45	...
1806*	. .	D. M. 63°, 1618	5.7	19.5	0.96	63 37	11.47	...
1807	7037	Draconis	5.8	19 33	0.29	68 29 45.4	11.43	− .03
1808*	. .	Vulpeculæ	5.6	20.4	2.65	21 01	11.53	...
1809	7061	40 Cygni	5.8	23 07	2.22	38 02 48.8	11.72	− .04
1810	7062	ω^1 Cygni	5.7	23 22	1.83	48 59 08.8	11.74	+ .04
1811	7067	41 Cygni	4.3	20 24 29	+ 2.45	29 58 08.5	+ 11.82	+ .01
1812	7065	1 Delphini	5.7	24 33	2.88	10 29 42.6	11.83	.00
1813	7085	ω^2 Cygni (pr.)	5.1	26 21	1.86	48 32 56.4	11.95	+ .02
1814	7086	Cygni	5.8	26 27	1.50	55 39 57.0	11.96	...
1815*	. .	Vulpeculæ	6.0	26.8	2.56	25 24	11.98	...
1816	7088	ε Delphini	4.1	27 29	2.87	10 53 47.1	12.03	− .03
1817	7098	ϑ Cephei	3.8	27 34	1.02	62 35 27.7	12.04	− .05
1818	7091	ω^2 Cygni (sq.)	5.4	27 36	1.85	48 48 57.5	12.04	− .03
1819	. .	D. M. 51°, 2882	5.8	27 55	1.71	51 54 02.3	12.06	.00
1820	7094	η Delphini	5.5	28 16	2.84	12 37 02.7	12.09	+ .08
1821	7103	47 Cygni	5.1	20 29 14	+ 2.34	34 50 25.2	+ 12.15	− .05
1822	7107	ζ Delphini	4.6	29 42	2.81	14 15 41.3	12.18	+ .04
1823	7112	Cygni	5.8	29 59	1.96	46 16 56.8	12.21	.00
1824	7121	β Delphini	3.8	31 55	2.81	14 10 44.0	12.34	− .01
1825	7126	27 Vulpeculæ	5.8	31 58	2.56	26 02 44.0	12.34	+ .02
1826	7125	ι Delphini	5.1	32 05	2.87	10 57 34.9	12.35	− .01
1827	7122	71 Aquilæ	4.6	32 08	3.10	− 1 31 21.4	12 35	+ .02
1828	. .	Cygni	5.8	32 53	2.25	37 54 44.5	12.41	...
1829	7137	ϑ Delphini	5.5	33 04	2.83	12 53 40.9	12.42	− .01
1830	7156	73 Draconis	5.3	33 04	− 0.73	74 32 34.5	12.42	− .03
1831	7140	29 Vulpeculæ	4.7	20 33 10	+ 2.68	20 46 51.7	+ 12.43	+ .01
1832	7138	1 Aquarii	5.2	33 16	3.08	0 03 56.4	12.44	− .03
1833	7143	28 Vulpeculæ	5.2	33 18	2.61	23 41 45.5	12.43	+ .01
1834	7141	κ Delphini	5.2	33 18	2.92	9 39 52.9	12.44	+ .02
1835	7146	D. M. 15°, 4220	5.8	33 31	2.78	15 25 04.3	12.45	+ .02
1836*	. .	Vulpeculæ	5.8	33.8	2.66	21 24	12.47	...
1837	7149	α Delphini	3.8	34 04	2.79	15 29 23.2	12.49	+ .03
1838	7158	Cygni	5.9	35 10	2.19	40 09 20.9	12.56	.00
1839	7160	10 Delphini	5.8	35 39	2.81	14 09 26.5	12.59	+ .03
1840	7178	75 Draconis	5.6	35 42	− 3.50	81 00 37.9	12.60	.00
1841*	. .	Cygni	5.7	20 35.8	+ 2.10	43 02	+ 12.61	...
1842	7164	49 Cygni	5.6	36 11	2.43	31 52 53.2	12.63	+ .03
1843	7171	α Cygni	1.5	37 20	2.04	44 51 07.6	12.71	.00
1844	7174	Cygni	5.5	37 36	2.16	41 17 15.9	12.73	.00
1845	7173	δ Delphini	4.2	37 51	2.80	14 38 41.8	12.75	− .02
1846	7182	51 Cygni	5.6	38 31	1.86	49 54 33.5	12.79	− .04
1847	7188	30 Vulpeculæ	5.4	39 41	2.60	24 50 31.8	12.87	− .17
1848	7194	52 Cygni	4.4	40 43	2.48	30 16 56.2	12.93	+ .01
1849	7200	γ Delphini	4.2	41 05	2.78	15 41 34.6	12.90	− .15
1850*	. .	Cephei	6.0	41.1	1.56	56 03	12.96	...

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1851	7204	ε Cygni	2.8	20 41 22	+ 2.42	33 31 17.3	+ 12.98	+ .32
1852	7211	4 Cephei	5.4	41 40	0.76	66 13 15.3	13.00	− .01
1853	7206	13 Delphini	5.5	41 52	2.98	5 34 07.1	13.02	...
1854	7215	Cephei	4.7	42 22	1.49	57 08 58.7	13.05	− .19
1855	. .	T Cygni	var. 5–6	42 23	2.39	33 56 01.8	13.05	...
1856	7213	λ Cygni	4.6	42 44	2.33	36 03 01.8	13.07	+ .02
1857	7220	η Cephei	3.6	42 51	1.23	61 22 23.7	13.08	+ .87
1858*	. .	Cygni	5.5	43.9	1.98	47 23	13.15	...
1859	7223	15 Delphini	5.6	43 55	2.86	12 05 52.5	13.15	+ .30
1860	7222	14 Delphini	5.7	43 55	2.94	7 25 12.8	13.15	+ .05
1861	. .	Cygni	6.0	20 44 17	+ 1.78	51 58 16.2	+ 13.18	...
1862	7233	55 Cygni	4.9	44 51	2.04	45 40 10.8	13.21	+ .01
1863*	. .	Cygni	6.0	45.1	1.81	51 28	13.23	...
1864	7241	56 Cygni	5.0	45 49	2.13	43 36 28.3	13.27	+ .13
1865*	. .	Delphini	6.0	47.0	2.76	17 34	13.35	...
1866	7246	31 Vulpeculæ	4.9	47 00	2.57	26 38 55.8	13.35	− .01
1867	7253	57 Cygni	4.9	49 00	2.12	43 56 00.8	13.48	.00
1868*	. .	Cygni	6.0	49.0	2.43	32 59	13.48	...
1869	7256	32 Vulpeculæ	5.2	49 27	2.55	27 36 07.0	13.51	.00
1870	7255	Equulei	5.5	49 40	3.01	4 04 31.4	13.53	− .06
1871	7257	16 Delphini	5.4	20 49 55	+ 2.87	12 06 40.5	+ 13.54	+ .05
1872	7258	17 Delphini	5.3	49 56	2.84	13 15 52.9	13.54	+ .04
1873	7291	76 Draconis	5.8	51 11	− 3.99	82 05 08.3	13.62	− .03
1874	7268	Cygni	5.7	51 47	+ 2.02	46 57 29.9	13.66	+ .04
1875	7278	Cygni	5.6	52 36	1.90	50 16 05.2	13.71	.00
1876	7271	18 Delphini	5.3	52 39	2.89	10 22 36.2	13.71	− .10
1877	7277	ν Cygni	4.1	52 42	2.24	40 42 21.9	13.72	+ .01
1878	7275	33 Vulpeculæ	5.2	52 54	2.69	21 51 47.2	13.73	+ .08
1879	7299	Draconis	5.5	52 59	2.52	80 06 05.8	13.74	.00
1880	7281	D. M. 56°, 2515 . . .	5.8	53 04	1.60	56 25 32.8	13.74	− .04
1881	7276	1 Equulei (1st *) . . .	5.2	20 53 05	+ 3.00	3 50 03.5	+ 13.75	− .14
1882	7290	Cygni	5.4	54 02	2.15	44 00 15.7	13.80	.00
1883	7294	Cygni	5.5	54 39	1.92	49 59 45.7	13.84	− .10
1884*	. .	Delphini	5.7	55.0	2.74	18 52	13.87	...
1885	7301	f Cygni	5.3	55 45	2.03	47 03 10.8	13.91	− .01
1886	7311	Cephei	5.8	56 08	− 0.63	75 27 39.8	13.94	+ .05
1887	7310	Cephei	5.6	56 28	+ 1.47	58 58 11.0	13.96	− .05
1888	7306	60 Cygni	5.4	57 00	2.09	45 41 05.2	13.99	− .03
1889	7320	Cygni	6.0	58 26	2.32	38 11 00.9	14.08	− .02
1890	7318	3 Equulei	5.6	58 36	2.99	5 01 36.3	14.09	− .05
1891	. .	Cephei	5.7	20 58 51	+ 1.65	56 11 45.7	+ 14.11	...
1892	7332	Cygni	5.6	21 00 08	1.83	52 48 29.4	14.19	.00
1893	7333	ξ Cygni	4.0	00 34	2.18	43 26 59.6	14.22	+ .02
1894	7336	61 Cygni (pr.)	5.3	01 31	2.67	38 09 36.2	14.27	+3.22
1895	7337	61 Cygni (sq.)	5.6	01 33	2.68	38 09 26.0	14.27	+3.00
1896*	. .	149 Cygni	5.6	01.5	2.51	30 42	14.27	...
1897	7345	f² Cygni	4.4	02 28	2.06	47 10 01.0	14.33	+ .01
1898	7350	γ Equulei	4.4	04 30	2.92	9 38 56.2	14.46	− .18
1899	7363	Cephei	5.8	05 40	0.40	70 57 06.4	14.53	.00
1900	7365	Cygni	5.6	06 33	1.86	53 04 22.9	14.58	− .06

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1901	7368	ζ Cygni	3.4	21 07 50	+ 2.55	29 44 07.5	+ 14.65	− .07
1902	7372	δ Equulei	4.6	08 38	2.93	9 31 17.9	14.70	− .28
1903	7377	23 Cephei	5.8	08 45	1.52	59 29 35.6	14.71	− .04
1904	7380	α Equulei	4.2	09 49	3.00	4 45 10.0	14.77	− .09
1905	7385	τ Cygni	3.9	10 00	2.39	37 32 03.2	14.78	+ .47
1906	7398	σ Cygni	4.3	12 42	2.35	38 53 32.4	14.94	− .01
1907	7399	υ Cygni	4.4	12 59	2.46	34 23 38.3	14.96	+ .02
1908*	. .	D. M. 53°, 2588	5.6	13.3	1.88	53 30	14.98	...
1909	7401	D. M. 55°, 2549	5.8	13 39	1.80	55 17 37.2	15.00	− .11
1910	7402	A Cygni	5.2	13 59	2.23	43 26 29.7	15.02	.00
1911*	. .	Pegasi	5.8	21 14.8	+ 2.72	21 32	+ 15.07	...
1912	7405	9 Equulei	5.7	15 09	2.97	6 50 49.0	15.07	+ .01
1913	7411	Cygni	5.7	15 21	2.06	49 00 11.0	15.06	.00
1914	7410	Pegasi	5.7	15 38	2.69	23 21 05.8	15.11	.00
1915	7416	α Cephei	2.5	15 43	1.43	62 04 37.7	15.12	+ .01
1916	7417	Cephei	5.6	15 56	1.66	58 06 58.4	15.13	...
1917*	. .	Cygni	5.8	16.3	2.52	32 06	15.15	...
1918	7418	1 Pegasi	4.3	16 32	2.78	19 17 31.6	15.16	+ .09
1919	7428	6 Cephei	5.2	16 53	1.25	64 21 48.2	15.18	.00
1920	7421	β Equulei	5.0	16 56	2.98	6 18 00.0	15.18	+ .05
1921	7438	Cephei	5.8	21 17 01	− 0.50	76 30 22.6	+ 15.19	+ .02
1922	7431	Cygni	5.8	17 50	+ 2.08	48 52 29.3	15.24	.00
1923	7437	Pegasi	5.7	18 34	2.70	23 45 35.7	15.28	+ .06
1924	. .	Cygni (sq.)	6.5	18 57	2.42	36 50 14.7	15.30	...
1925	7444	Vulpeculæ	5.3	19 14	2.65	25 39 29.7	15.32	− .11
1926	7455	Cygni	5.8	20 53	2.18	46 11 42.6	15.41	+ .05
1927	7453	69 Cygni	5.8	20 53	2.45	36 08 58.7	15.41	+ .01
1928	7461	35 Vulpeculæ	5.3	22 23	2.65	27 05 13.7	15.50	+ .07
1929	7462	70 Cygni	5.0	22 28	2.45	36 35 44.7	15.50	− .02
1930*	. .	Cygni	5.4	22.6	2.12	48 19	15.51	...
1931	7468	Cygni	5.7	21 22 48	+ 1.97	52 22 39.8	+ 15.52	− .01
1932	7465	Cygni	5.7	23 01	2.56	31 42 03.4	15.53	+ .09
1933*	. .	Pegasi	5.6	23.5	2.74	21 40	15.56	...
1934	7474	2 Pegasi	4.6	24 31	2.72	23 06 49.8	15.61	+ .02
1935	7480	g Cygni	5.3	25 01	2.20	46 00 42.7	15.64	+ .11
1936*	. .	Pegasi	5.8	25.3	2.90	11 37	15.66	...
1937	7482	7 Cephei	5.4	25 27	1.17	66 17 08.5	15.66	− .04
1938	7493	β Cephei	3.2	27 06	0.80	70 02 01.1	15.75	− .04
1939	7495	Cephei	5.5	27 42	1.65	59 55 50.0	15.79	.00
1940	7510	Cephei	6.0	28 20	− 1.57	80 00 04.7	15.82	− .02
1941*	. .	Cygni	6.0	21 28.7	+ 2.11	49 25	+ 15.84	...
1942	7503	ρ Cygni	4.1	29 28	2.25	45 03 43.5	15.88	− .05
1943	7505	72 Cygni	5.1	29 53	2.45	37 59 48.8	15.90	+ .12
1944	7521	74 Cygni	5.1	32 08	2.40	39 52 30.1	16.02	+ .01
1945	7520	5 Pegasi	5.5	32 09	2.81	18 46 47.0	16.02	+ .09
1946	7528	Pegasi	5.8	33 25	2.78	19 43 28.3	16.09	.00
1947	7527	d Aquarii	5.2	33 28	3.05	1 42 17.7	16.09	− .02
1948	7542	9 Cephei	5.1	34 42	1.61	61 32 28.0	16.16	+ .02
1949	7544	75 Cygni	5.1	35 29	2.35	42 43 46.2	16.20	+ .03
1950	7546	26 Aquarii	5.7	36 03	3.07	0 44 21.2	16.23	− .02

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
1951	7547	7 Pegasi	5.4	21 36 15	+ 3.01	5 08 02.5	+ 16.24	− .05
1952	7555	D. M. 54°, 2595	5.8	36 45	1.98	54 19 36.0	16.26	.00
1953	7559	77 Cygni	5 8	37 33	2.41	40 31 46.6	16.30	− .02
1954	7560	π^1 Cygni	4.9	37 50	2.12	50 38 32.3	16.31	− .01
1955	7565	Cygni	5.4	38 17	2.40	49 36 25.5	16.34	+ .02
1956	7561	ε Pegasi	2.7	38 18	2.95	9 19 32.5	16.34	.00
1957	7566	79 Cygni	5.6	38 28	2.47	37 44 05.8	16.35	.00
1958	7568	μ Cygni (1st *)	4.6	38 47	2.67	28 12 04.5	16.37	− .26
1959	7567	9 Pegasi	4.1	38 50	2.85	16 48 02.6	16.37	+ .06
1960	7571	κ Pegasi	4.2	39 13	2.72	25 05 38.8	16.39	+ .03
1961	7582	μ Cephei	var. 4.5–6.4	21 39 50	+ 1.83	58 13 48.8	+ 16.42	+ .01
1962	7588	11 Cephei	4.9	40 10	0.90	70 45 31.6	16.43	+ .07
1963	7585	12 Pegasi	5.1	40 33	2.76	22 23 47.3	16.45	+ .05
1964	7587	11 Pegasi	5.4	41 09	3.05	2 07 55.7	16.49	+ .08
1965	7590	D. M. 16°, 4598	5.8	41 22	2.86	16 38 24.4	16.49	...
1966	7597	Cephei	5.4	41 36	0.75	71 46 12.8	16.51	− .02
1967	7595	ν Cephei	4.6	41 59	1.73	60 34 01.9	16.53	− .03
1968	7598	π^2 Cygni	4.4	42 22	2.21	48 45 16.4	16.54	− .01
1969	7605	12 Cephei	5.8	43 53	1.77	60 08 09 0	16.62	− .03
1970	7606	13 Pegasi	5.3	44 26	2.86	16 43 42.7	16.64	− .01
1971	7607	14 Pegasi	5.1	21 44 32	+ 2.65	29 36 58.3	+ 16.65	− .01
1972	. .	Pegasi	5.6	45 56	2.81	19 15 52.4	....	...
1973	7623	15 Pegasi	5.9	47 09	2.67	28 13 57.9	16.78	− .04
1974	7627	16 Pegasi	5.4	47 36	2.73	25 21 39.6	16.79	− .01
1975	7631	Cygni	5.8	47 57	2.02	55 13 58.3	16.82	− .06
1976*	. .	Pegasi	5.5	48.0	2.82	19 06	16.82	...
1977*	. .	D. M. 20°, 5046	5.6	50.8	2.80	20 42	16.95	...
1978	7641	17 Pegasi	5.5	51 06	2.93	11 30 27.6	16.96	+ .04
1979	7658	Cephei	5.5	53 17	1.70	63 03 15.2	17.06	− .02
1980	7659	18 Pegasi	5.6	54 08	3.00	6 08 34.6	17.11	+ .04
1981	7660	28 Aquarii	5.6	21 54 57	+ 3.07	0 01 45.0	+ 17.14	− .05
1982	7662	19 Pegasi	5.6	55 12	2.98	7 40 52.7	17.15	+ .01
1983	7664	20 Pegasi	5.8	55 14	2.92	12 32 46.0	17.15	.00
1984	7676	Cygni	5.5	57 27	2.19	52 18 14.5	17.26	.00
1985	7686	16 Cephei	5.1	57 32	0.88	72 36 30.9	17.27	− .19
1986	7681	Lacertæ	5.8	58 06	2.41	44 04 19.0	17.29	.00
1987	7685	32 Aquarii	5.6	58 37	3.09	− 1 29 09.2	17.30	− .03
1988	7688	α Aquarii	3.7	59 37	3.08	− 0 54 08.2	17.35	− .00
1989	7689	ν Pegasi	4.9	59 38	3.03	4 28 22.1	17.35	+ .09
1990	7693	23 Pegasi	5.6	22 00 09	2.71	28 22 54.4	17.37	+ .04
1991	7699	18 Cephei	5.7	22 00 17	+ 1.78	62 32 08.6	+ 17.38	...
1992	7700	ξ Cephei (2d *)	4.5	00 19	1.74	64 02 36.6	17.38	+ .08
1993	7705	Lacertæ	5.3	01 10	2.40	44 25 49.8	17.42	− .10
1994	7707	20 Cephei	5.7	01 22	1.82	62 12 00.8	17.42	+ .04
1995	7706	ι Pegasi	4.0	01 25	2.79	24 45 34.5	17.43	+ .02
1996	7708	19 Cephei	5.6	01 28	1.87	61 41 46.3	17.43	− .02
1997	7712	25 Pegasi	5.6	02 12	2.82	21 07 09.7	17.46	− .01
1998	7721	π Pegasi (pr.)	5.5	03 55	2.65	32 35 13.3	17.53	− .03
1999	7723	ϑ Pegasi	3.7	04 09	3.03	5 36 29.6	17.55	+ .05
2000	7731	π Pegasi (sq.)	4.1	04 39	2.66	32 35 24.5	17.56	+ .03

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
2001*	. .	Pegasi	6.0	22 04.8	+ 2.95	11 02	+ 17.57	...
2002	7733	28 Pegasi	5.8	04 50	2.83	20 23 19.8	17.57	.00
2003	7746	Lacertæ	5.5	06 30	2.31	50 13 50.3	17.64	.00
2004	7749	ζ Cephei	3.6	06 41	2.07	57 36 35.5	17.65	− .01
2005	7755	λ Cephei	5.4	07 26	2.03	58 49 21.3	17.68	− .04
2006	7754	Cephei	5.8	07 29	2.15	56 14 35.1	17.69	+ .16
2007	7753	Pegasi	5.5	07 29	2.66	34 00 47.6	17.69	− .10
2008	7758	24 Cephei	5.0	07 30	1.16	71 44 59.8	17.69	− .03
2009	7760	Cephei	5.7	07 54	1.39	69 32 24.4	17.70	+ .08
2010	7759	Cephei	5.5	08 04	1.98	60 09 56.0	17.71	...
2011	7765	Lacertæ	4.8	22 08 44	+ 2.58	39 07 07.8	+ 17.74	− .16
2012	. .	Lacertæ	5.8	08 53	2.45	44 50 44.5	17.74	...
2013	7770	Lacertæ	5.8	09 41.	2.51	42 21 33.8	17.77	.00
2014	7778	ε Cephei	4.7	10 37	2.20	56 26 29.8	17.81	+ .02
2015	7777	1 Lacertæ	4.6	10 44	2.61	37 09 06.4	17.81	+ .02
2016	7789	25 Cephei	6.1	14 17	1.94	62 12 10.5	17.96	.00
2017	7796	31 Pegasi	5.1	15 37	2.95	11 36 04.2	18.01	+ .04
2018	7798	32 Pegasi	4.8	15 47	2.76	27 43 36.2	18.02	+ .01
2019	7800	2 Lacertæ	4.8	16 04	2.47	45 55 57.9	18.03	+ .02
2020	7807	33 Pegasi	6.1	17 53	2.89	20 14 32.2	18.10	− .02
2021	7815	3 Lacertæ	4.7	22 18 51	+ 2.35	51 37 41.0	+ 18.13	− .21
2022	7814	π Aquarii	4.5	19 09	3.06	0 46 08.3	18.14	− .01
2023	7820	4 Lacertæ	4.9	19 39	2.42	48 52 05.6	18.16	− .02
2024	7823	34 Pegasi	5.8	20 31	3.06	3 46 54.6	18.19	+ .05
2025	7827	35 Pegasi	5.1	21 47	3.04	4 05 41.4	18.24	− .29
2026*	. .	Lacertæ	5.8	22.2	2.62	39 12	18.25	...
2027	7851	Cephei	5.0	22 38	− 3.90	85 30 10.9	18.27	+ .04
2028*	. .	Cephei	5.6	22.7	+ 1.55	70 09	18.27	...
2029	7832	ζ Aquarii	3.9	22 39	3.09	− 0 38 00.2	18.27	+ .03
2030	7833	36 Pegasi	5.7	23 09	3.00	8 31 00.8	18.29	− .01
2031	7837	26 Cephei	5.7	22 23 14	+ 1.92	64 31 12.8	+ 18.29	− .04
2032*	. .	Pegasi	5.5	23.5	2.80	26 09	18.30	...
2033	7845	5 Lacertæ	4.5	24 32	2.50	47 05 35.3	18.34	+ .01
2034	7843	38 Pegasi	5.4	24 33	2.74	31 57 33.5	18.34	+ .11
2035	7848	δ Cephei	var. 3.8–4.7	24 43	2.21	57 48 04.1	18.34	− .02
2036	7850	6 Lacertæ	4.9	25 18	2.57	42 30 31.5	18.37	.00
2037	7857	28 Cephei	5.9	25 47	0.52	78 10 26.4	18.38	− .06
2038	7855	7 Lacertæ	4.0	26 21	2.46	49 39 56.1	18.40	− .01
2039	7874	ρ Cephei	5.9	28 48	0.59	78 12 30.1	18.48	− .03
2040	7868	η Aquarii	4.0	29 11	3.08	− 0 44 07.8	18.50	− .06
2041	7876	Cephei	6.0	22 29 34	+ 1.73	69 17 34.6	+ 18.51	+ .23
2042	7881	Cephei	5.4	30 10	1.11	75 36 28.5	18.53	− .01
2043	7880	8 Lacertæ (2d *)	5.3	30 32	2.66	39 00 48.9	18.54	− .02
2044	7888	9 Lacertæ	5.3	32 27	2.46	50 55 34.7	18.61	− .08
2045	7896	31 Cephei	5.3	32 49	1.49	73 01 13.5	18.62	+ .04
2046	7893	40 Pegasi	5.8	33 04	2.90	18 54 07.0	18.63	− .07
2047	7901	10 Lacertæ	4.9	33 53	2.68	38 25 34.2	18.65	+ .02
2048	. .	Cephei	5.8	33 55	2.34	56 10 21.8	18.65	...
2049*	. .	Lacertæ	5.8	34.2	2.70	36 58	18.66	...
2050	7902	30 Cephei	5.3	34 24	2.11	62 57 38.9	18.67	− .02

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
2051	. .	Pegasi	5.7	22 34 55	+ 2.95	13 55 02.7	+ 18.69	. . .
2052	7906	11 Lacertæ	4.6	35 15	2.62	43 39 01.0	18.70	.00
2053	. .	Lacertæ	5.8	35 26	2.42	53 13 14.7	18.70	. . .
2054	7908	ζ Pegasi	3.5	35 29	2.99	10 12 19.8	18.71	.00
2055	7915	12 Lacertæ	5.4	36 06	2.68	39 35 55.9	18.72	− .01
2056	7914	ο Pegasi	4.6	36 08	2.81	28 40 54.4	18.72	− .01
2057	7923	η Pegasi	3.1	37 22	2.81	29 35 39.2	18.76	− .01
2058	. .	D. M. 53°, 2960 . . .	5.8	37 26	2.44	53 16 51.7	18.76	. . .
2059	7932	13 Lacertæ	5.3	38 45	2.67	41 11 24.0	18.80	+ .02
2060	7943	ξ Pegasi	4.6	40 42	2.99	11 33 28.9	18.86	− .49
2061	7945	λ Pegasi	3.9	22 40 45	+ 2.88	22 56 04.9	+ 18.87	+ .02
2062	7948	Lacertæ	6.0	40 50	2.63	43 54 49.1	18.87	.00
2063	. .	D. M. 36°, 4934 . . .	5.8	42 41	2.74	36 47 09.7	18.92	. . .
2064	. .	Lacertæ	6.0	43 49	2.47	53 46 51.0	18.95	. . .
2065	. .	Cephei	6.0	44 13	2.24	62 18 21.4	18.97	.00
2066	7958	μ Pegasi	3.8	44 13	2.88	23 58 06.3	18.97	− .04
2067	7961	D. M. 55°, 2820 . . .	5.7	44 49	2.45	55 15 58.3	18.98	.00
2068	7967	ι Cephei	3.6	45 25	2.12	65 34 09.6	19.00	− .14
2069	7971	σ Pegasi	4.9	46 19	3.05	9 11 51.8	19.02	+ .06
2070	7972	15 Lacertæ	5.1	46 37	2.69	42 40 29.4	19.03	.00
2071	7973	Cephei	5.8	22 46 41	+ 2.31	61 03 32.8	+ 19.04	+ .07
2072	7975	Pegasi	5.4	47 08	2.95	16 12 18.2	19.05	− .01
2073	7990	Cephei	4.9	47 54	− 0.07	82 31 01.7	19.07	+ .07
2074	7983	Lacertæ	6.0	48 18	+ 2.67	44 06 41.5	19.08	.00
2075	7984	Lacertæ	5.7	48 36	2.73	39 44 14.4	19.09	.00
2076	7988	ρ Pegasi	4.8	49 11	3.02	8 10 35.9	19.10	+ .05
2077*	. .	Lacertæ	5.7	49.5	2.77	36 27	19.11	. . .
2078*	. .	Lacertæ	5.8	50.09	2.78	35 42 39.8	19.13	. . .
2079	7995	Lacertæ	5.1	51 10	2.61	49 05 35.3	19.13	.00
2080	7997	51 Pegasi	5.3	51 34	2.95	20 07 33.2	19.14	+ .07
2081	7999	Lacertæ	5.4	22 51 46	+ 2.63	48 02 36.1	+ 19.17	.00
2082	8005	2 Piscium	5.8	53 18	3.08	0 19 20.3	19.21	− .12
2083*	. .	D. M. 51°, 3514 . . .	5.8	53 59	2.59	52 00 37.3	19.23	.00
2084*	. .	D. M. 30°, 4859 . . .	5.8	55.0	2.85	30 27	19.25	. . .
2085*	. .	D. M. 56°, 2923 . . .	5.8	55.1	2.51	56 18	19.25	. . .
2086	8026	Cephei	5.0	55 19	− 0.23	83 42 14.7	19.26	+ .05
2087	8023	ο Andromedæ	3.8	56 24	+ 2.75	41 40 54.4	19.28	+ .03
2088*	. .	D. M. 22°, 4762 . . .	5.8	56.5	2.92	22 40	19.29	. . .
2089	8031	β Piscium	4.6	57 46	3.05	3 10 26.9	19.32	− .02
2090	8032	β Pegasi	var. 2.5–2.8	57 57	2.90	27 25 56.3	19.32	+ .15
2091	8034	α Pegasi	2.4	22 58 47	+ 2.99	14 33 36.5	+ 19.34	− .02
2092	8036	3 Andromedæ	4.7	58 48	2.68	49 23 59.1	19.34	+ .12
2093	8039	Cephei	5.3	58 59	2.26	66 33 45.0	19.35	+ .04
2094	8051	55 Pegasi	5.0	23 00 58	3.03	8 45 42.9	19.39	+ .01
2095	8052	56 Pegasi	5.1	01 16	2.92	24 49 15.5	19.40	− .03
2096	8054	1 Cassiopeæ	5.0	01 33	2.52	58 46 17.0	19.40	− .01
2097	. .	D. M. 52°, 3371 . .	5.4	01 51	2.63	52 10 02.4	19.41	. . .
2098	8058	4 Andromedæ	5.4	02 10	2.73	45 44 22.0	19.42	− .03
2099	8059	5 Andromedæ	5.7	02 19	2.71	48 38 32.2	19.42	+ .13
2100	8060	A Piscium	5.6	02 32	3.07	1 28 29.6	19.42	+ .10

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
2101	8070	57 Pegasi	5.3	23 03 28	+ 3.03	8 01 37.3	+ 19.45	+ .01
2102	8071	58 Pegasi	5.3	03 59	3.02	9 10 19.4	19.46	+ .04
2103	8074	π Cephei	4.6	04 05	1.89	74 44 19.2	19.46	− .04
2104	. .	Pegasi	5.7	04 45	2.97	16 56 42.1	19.47	...
2105	8076	6 Andromedæ	6.0	04 55	2.76	42 54 00.7	19.48	− .14
2106	8078	59 Pegasi	5.4	05 41	3.03	8 04 08.0	19.49	+ .01
2107	8082	7 Andromedæ	4.8	07 03	2.73	48 45 02.9	19.52	+ .08
2108	8083	Cassiopeæ	5.8	07 30	2.86	56 30 20.8	19.53	+ .28
2109	8105	γ Piscium	3.9	10 57	3.11	2 37 35.8	19.60	− .01
2110	8106	Cephei	5.6	11 00	2.28	70 14 01.0	19.60	− .01
2111	8107	Andromedæ	5.5	23 11 14	+ 2.70	52 33 58.6	+ 19.60	− .28
2112	8114	8 Andromedæ	4.9	12 11	2.76	48 21 35.4	19.62	.00
2113	8124	ο Cephei	5.1	13 42	2.44	67 27 17.5	19.64	− .02
2114	8125	11 Andromedæ	5.5	13 55	2.78	47 58 01.1	19.65	+ .03
2115	8128	10 Andromedæ	5.9	14 10	2.85	41 25 18.4	19.65	+ .05
2116	8127	b Piscium	5.4	14 14	3.06	4 43 35.6	19.65	− .04
2117	8131	τ Pegasi	4.8	14 42	2.96	23 05 01.5	19.66	− .01
2118	8136	12 Andromedæ	5.8	15 06	2.89	37 31 39.5	19.67	− .05
2119	8138	Cassiopeæ	5.8	15 20	2.59	61 33 24.2	19.67	+ .04
2120	8141	64 Pegasi	5.7	16 04	2.92	31 09 18.7	19.68	+ .02
2121	8149	66 Pegasi	5.3	23 17 01	+ 3.02	11 39 24.6	+ 19.70	+ .03
2122	8153	Cassiopeæ (sq.)	6.1	17 12	2.65	59 28 32.6	19.70	+ .01
2123	8159	67 Pegasi	5.8	18 58	2.93	31 43 33.9	19.73	.00
2124	8160	υ Pegasi	4.5	19 23	2.99	22 44 37.9	19.74	+ .07
2125	8162	4 Cassiopeæ	5.3	19 31	2.64	61 37 27.4	19.74	+ .02
2126	8169	κ Piscium	5.3	20 47	3.08	0 35 55.0	19.76	− .12
2127	8177	ϑ Piscium	4.6	21 53	3.04	5 43 13.0	19.78	− .03
2128	8182	70 Pegasi	4.8	23 05	3.03	12 05 55.6	19.79	+ .06
2129	8188	Cassiopeæ	5.5	24 30	2.76	57 53 15.5	19.81	+ .02
2130	8195	14 Andromedæ	5.6	25 23	2.94	38 34 38.2	19.82	− .05
2131*	. .	Pegasi	6.0	23 25.5	+ 2.96	28 00	+ 19.82	...
2132	8203	71 Pegasi	5.6	27 28	3.00	21 50 13.0	19.85	− .02
2133*	. .	Pegasi	5.8	27.9	3.00	20 11	19.85	...
2134	8213	Cephei	6.0	27 50	− 0.04	86 38 43.4	19.85	.00
2135	8206	72 Pegasi	5.1	28 00	+ 2.96	30 39 46.8	19.86	− .02
2136	8211	73 Pegasi	5.9	28 42	2.96	32 50 02.3	19.86	+ .06
2137	8212	15 Andromedæ	5.8	28 45	2.92	39 34 30.5	19.86	− .03
2138	8217	Cephei	6.0	29 46	2.56	70 58 44.0	19.88	+ .01
2139	8224	λ Andromedæ	3.9	31 42	2.92	45 48 29.3	19.90	− .39
2140	8227	75 Pegasi	5.5	31 53	3.02	17 44 10.2	19.90	+ .07
2141	8229	ι Andromedæ	4.4	23 32 15	+ 2.92	42 36 14.1	+ 19.91	+ .02
2142	8231	18 Andromedæ	5.5	33 20	2.89	49 48 25.4	19.92	− .02
2143	8234	Pegasi	5.8	33 49	3.06	9 00 46.2	19.92	− .03
2144	8233	ι Piscium	4.3	33 47	3.08	4 58 32.7	19.92	− .45
2145	. .	Cephei	5.8	34 08	2.56	73 20 15.2	19.93	.00
2146	8238	γ Cephei	3.5	34 26	2.40	76 57 45.5	19.93	+ .15
2147	8237	κ Andromedæ	4.4	34 30	2.93	43 40 12.0	19.93	+ .02
2148*	. .	Andromedæ	6.0	34.7	2.96	36 03	19.93	...
2149	8243	λ Piscium	4.7	35 55	3.06	1 07 10.0	19.94	− .17
2150	. .	D. M. 63°, 2038	5.8	36 41	2.78	63 51 00.2	19.95	...

CATALOGUE OF STARS FOR OBSERVATIONS OF LATITUDE.

No.	B. A. C.	Constellation.	Mag.	A. R. 1880.	Annual Variation.	Declination 1880.	Annual Precession.	Proper Motion.
				h. m. s.	s.	° ′ ″	″	″
2151	8250	77 Pegasi	5.1	23 37 16	+ 3.05	9 39 55.8	+ 19.95	.00
2152	8256	78 Pegasi	5.0	37 57	3.01	28 41 50.1	19.96	+ .01
2153	8261	ψ Andromedæ	5.1	40 05	2.95	45 45 14.8	19.98	− .01
2154*	. .	Cassiopeæ	6.0	41.2	2.90	56 47	19.98	...
2155	8268	τ Cassiopeæ	5.1	41 12	2.90	57 59 01.2	19.98	+ .06
2156	8273	Cephei	5.3	42 11	2.83	67 08 24.5	19.99	− .01
2157	8279	6 Cassiopeæ	5.8	43 00	2.88	61 32 53.0	20.00	+ .04
2158*	. .	Andromedæ	5.7	43.6	3.00	35 46	20.00	...
2159	8296	Pegasi	5.5	46 18	3.04	21 00 14.1	20.02	+ .02
2160	8299	φ Pegasi	5.2	46 23	3.04	18 27 14.9	20.02	+ .01
2161	8300	82 Pegasi	5.7	23 46 30	+ 3.06	10 16 46.4	+ 20.02	− .04
2162	8310	ρ Cassiopeæ	4.7	48 24	2.96	56 49 55.6	20.03	− .01
2163*	. .	D. M. 46°, 4214	5.7	49 30	3.00	46 41 17.5	20.03	...
2164*	. .	Pegasi	5.8	50.6	3.05	21 59	20.04	...
2165	8321	Cephei	6.0	50 51	2.68	82 31 21.3	20.04	− .04
2166	. .	Andromedæ	5.8	50 59	3.02	41 59 25.6	20.04	...
2167	8322	Cassiopeæ	5.8	51 06	3.00	55 02 16.9	20.04	− .05
2168	8324	ψ Pegasi	4.4	51 39	3.05	24 28 28.9	20.04	− .01
2169	8330	σ Cassiopeæ	4.8	52 55	3.01	55 05 13.5	20.04	− .02
2170	8331	ω Piscium	4.2	53 09	3.08	6 11 55.9	20.04	− .13
2171*	. .	Andromedæ	5.7	23 53.4	+ 3.05	33 04	+ 20.04	...
2172*	. .	D. M. 44°, 4538	5.8	54.6	3.03	44 35	20.05	...
2173	8344	Cassiopeæ	6.0	55 30	3.02	60 33 16.2	20.05	− .01
2174*	. .	D. M. 16°, 5034	5.8	57.1	3.07	16 52	20.05	...
2175	8359	9 Cassiopeæ	5.5	58 03	3.05	61 37 10.8	20.05	+ .02
2176	. .	D. M. 41°, 4923	6.4	58 27	3.06	41 25 31.0	20.05	...
2177	. .	Cephei	5.8	58 28	3.04	66 29 49.8	20.05	...
2178	8366	Cassiopeæ	5.8	58 54	3.06	60 38 43.7	20.05	...
2179	8370	86 Pegasi	5.5	59 32	3.07	12 43 43.2	20.05	+ .04

APPENDIX No. 8.

METHODS OF REGISTERING TIDAL OBSERVATIONS, BY R. S. AVERY.

The method proper for observing and recording tidal observations at any place depends upon the character of the tides there, and the amount of rise and fall. In general, all tidal changes that occur by day and by night should be observed during a lunation, or a certain number of lunations, or, preferably, during an entire lunar declination period. Day-tides alone will not suffice for establishing correct tide-levels, unless the night-tides at the same place are alike, nor in any case in which only one well-defined high water occurs in twenty-four hours. For close investigations a record showing only time and height for successive tides is insufficient. At places distant from the sea the time of transmission is less for a large tide than for a small one; hence the importance of knowing the range of tides in height, and this necessitates the observation of both high and low waters. As nothing short of incessant personal attention on the part of the observer could maintain the continuity desirable in the record, the utility of the apparatus to represent graphically all the peculiarities of each successive tide for a given period is obvious. The devices for such purpose are called *self-registering tide-gauges*, but as the aim of this paper is to note also the most ready and least expensive ways for securing reliable observations, the principle and method of using the self-registering gauge will be described further on. The *staff-gauge* will be mentioned first, but, as preliminary to any record of height, attention must be given to what immediately follows.

BENCH-MARKS.

Whatever method for observing tides may be adopted, it is very important to have one or more marks on a permanent bench of rock or other durable basis near the tide-gauge, and to know, by leveling, the exact height of the marks above the zero of the tide-gauge. Bench-marks are made by drilling holes horizontally in rock, in the wall of a light-house, fort, or other stone or brick structure; or the top of a rock or top or bottom of a stone step may be taken, or the door or window sill of any adjacent building likely to be permanent. In the absence of such facilities in any vicinity a bench-mark may be made on a block of stone and buried out of sight. The position of the mark should be described in the record for identification, and of course its height above the zero of the tide staff or gauge. Any series of observations recorded with reference to a zero at a given distance below the *permanent* bench-mark can be readily repeated years after the removal of the tide-gauge; hence the importance of care in regard to the permanence and identification of bench-marks.

TIDE-GAUGES.

Near the open sea, where the violence of the waves will never admit of precise or continuous observations, the tidal record must be made by protecting the reading-scale or indicator. This is done by fixing upright, in a convenient place, a wooden box or tube, near the bottom of which the water may enter by an opening, quite small if the station is near the sea, but the proper size of the hole can be readily determined in any case by trial. Tides in harbors have been well determined when the sectional area of the hole for admitting water near the bottom of the float was $\frac{1}{100}$ to $\frac{1}{200}$ of that of the box itself, the lower end of the box being from 3 to 6 feet below the level of the lowest low waters. The stability of the box, and quiet water inside of it for the float to rest on, are the conditions to be sought in the construction and setting up of the box for operations. The orifice should be such as to render barely sensible the effect of ordinary wind-waves, and yet allow the registration of waves of longer duration. A very small hole suffices for this; but if too small, the record will be inaccurate. Earthquake-waves lasting twenty or thirty minutes have been well recorded by self-registering tide-gauges in the care of observers who had learned by experience the proper method of admitting the water into the float-box.

Staff-gauge.—The common way of measuring tides is by means of a staff made of wood, an inch or more thick, four inches or more in width, and at least three or four feet longer than the vertical rise and fall of the tides at the place of observation. Starting with zero always below the level of the lowest water to be observed at the station, one face of the staff is divided and numbered upward in feet and tenths, so that the numbers increase with the rise of the tide. The staff should be firmly fixed, and, if ten feet long, it should be at least six inches wide. The wooden staff will suffice for a season, but thick sheet-iron strips bearing the graduation in porcelain, and fastened to a plank, will be found serviceable during seven or eight successive years.

The staff-gauge answers well in harbors where the water is still enough to allow of reading the graduation with accuracy, and especially where only a short series of observations are required. But, if the water is even a little rough, a valuable attachment to the staff is a glass tube of half an inch or more in diameter, furnished with a colored float, which may be either a bubble of red glass or a few drops of tinted oil. The tube needs to be attached to the graduated face of the staff so that the tube may not slip. If the rise and fall is considerable, several pieces of glass tube may be attached to the same staff, if the tube-ends are properly joined by short rings of India rubber. Being in principle like the float-box already described, the glass tubing must be extended well under the level of low-water, and the lower end of the tube should be stoppered, so as to subject only one-eighth or one-tenth of the sectional area of the tube to tidal action. This device, of course, will not avail at times when ice forms readily.

Box-gauge.—Having a float-box about six inches square, stoutly made and firmly secured in place, and of length suitable to the average rise of the tide, the construction will be complete if the lower end of the box is funnel-shaped, so as to admit the water by a hole about six-tenths of an inch in diameter. The open pointed end makes the accumulation of mud or sand in the lower part of the box impossible. Within the box is placed a cylindrical water-tight float of sheet-copper about five inches in diameter and somewhat less in height. The top of the float bears a socket, in which is inserted a light graduated staff numbered in feet and tenths from above downward, and the staff is to move freely up and down through a hole in the square board that covers the top of the box, above which all the graduation on the tide-staff is to be read off by the observer. For that purpose a mark called the *reading-point* is to be firmly fixed at the top near the staff, so that the observer may conveniently note the divisions on the staff as they pass the reading-point. That point must remain fixed during the series of observations, and to insure this it must be referred to some unchangeable bench-mark by levelings in advance of beginning the tidal record. The distance from the water-line on the copper float to the lowest division or zero on the staff should be recorded, to enable the computer to reduce all the measurements to the bench-mark, and the distance should be remeasured, and the result noted, if, by any accident, or increase of weight in the graduated stick by the absorption of water, the water-line on the float changes while the series of observations is in progress.

In some places submerged weeds may interfere with the upward rise of water through the bottom of the float-box; hence the outside of the box should be marked in feet and tenths, and comparison made occasionally between the outside reading and that given for the same tide in time and height by the graduated rod of the float.

Instead of a graduated rod, metallic tape may be substituted, of the kind used by surveyors. The tape is wound on a wheel five or six inches in diameter, the axle of which carries a pulley to receive the cord that has at one end the float, and at the other a weight to counterpoise the float. Among several ways in which this apparatus may be arranged for reading, it has been found convenient to divide the tape in feet only, and fix up near it over the box a rod one foot long subdivided into tenths and hundredths of a foot. Then, by carefully adjusting all parts of the apparatus, the height of the tide can easily be read to the nearest hundredth. So arranged, the lower end of this scale will be the fixed or *reading-point*, the numbers on the tape increasing downward so that the least numbers correspond to low waters.

In connection with the form of tide-gauge now under notice, other expedients suited to the circumstances of the place will readily suggest themselves. The graduated rod, or tape, has been made so as to move slides on a scale, or pointers on a dial, thus showing the height for the last

high and last low water. At intervals subsequently the observer reads his gauge and notes down the heights in his record, but of course has no record of the time of either high water or low water.

At stations exposed to the roughness of the open sea, a good method for recording the tides was devised some years ago, and will be found described in the Coast Survey Report for 1854. Several modifications of this mode have been in practice.

Apparatus for recording the tides by noting the changes in barometric pressure will be found described in the Coast Survey Report for 1858, but as that and each of the methods so far mentioned include no provision for conveniently recording the time of high and low water, much less the state of the tide at intermediate periods, the method which has been for some years employed at the permanent tidal stations of the Coast Survey will be now described, after a few remarks on the apparatus used for the observations.

SELF-REGISTERING TIDE-GAUGES.

So far as known to us, the first instrument for automatically registering the tides was used by Mr. Palmer, an engineer on the London docks in 1831, since which date several other devices for the same purpose have been used in England, France, Holland, and elsewhere. The first self-registering tide-gauge used in the United States was in the form devised by the late Mr. Joseph Saxton of the Office of United States Weights and Measures. That apparatus is fully described in the Coast Survey Report for 1853. The Saxton gauges were in use for some years, but being made light, and timed by pendulum-clocks, breaks in the record were likely to occur at any station where the apparatus could not rest on a solid pier. For these, therefore, have been substituted two forms of self-registering tide-gauges, one having large cylinders, designed by Mr. Robert S. Avery of the United States Coast Survey, Tidal Division, and the other is the Saxton gauge as improved by him, retaining the three small cylinders.

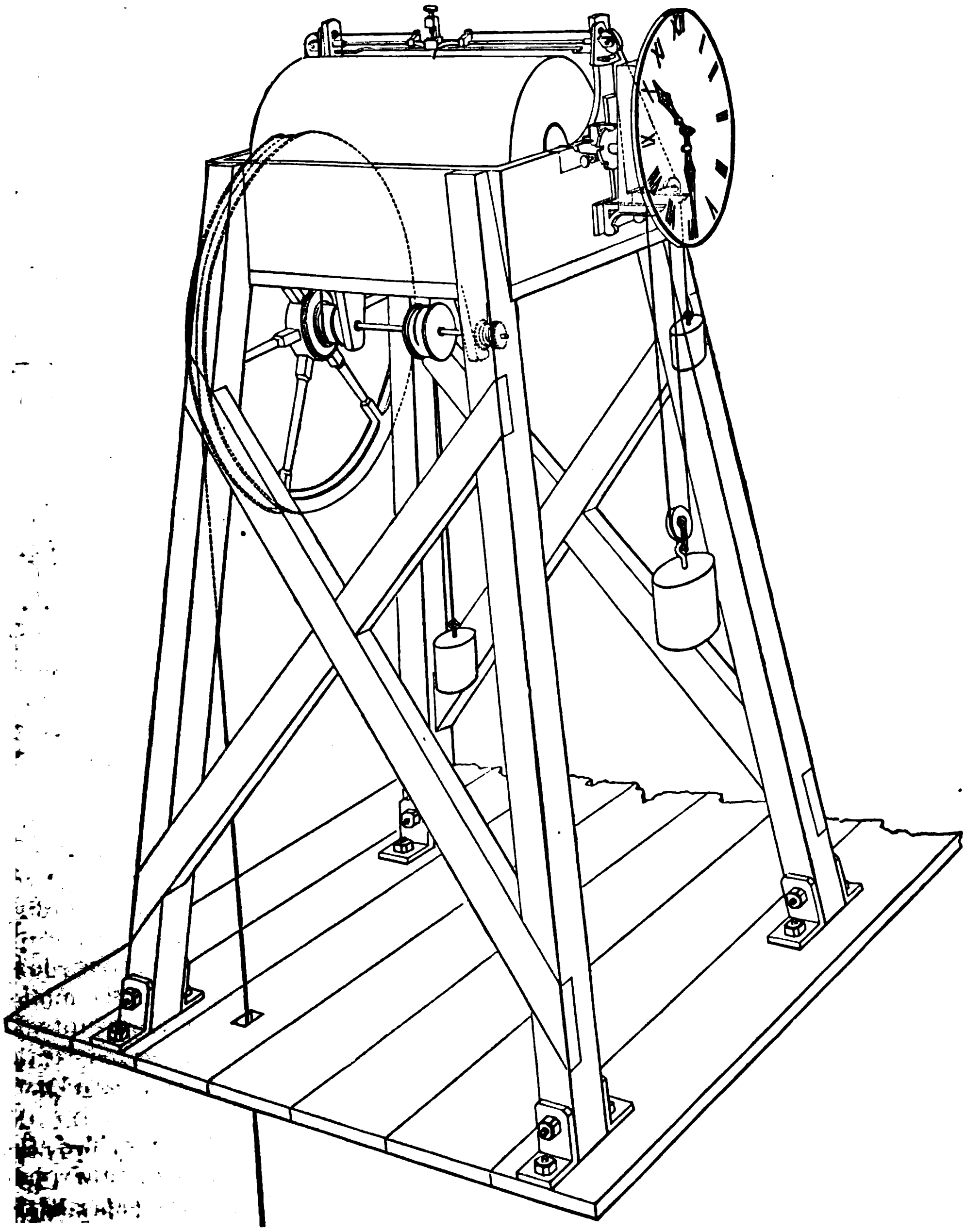
The following description will give an idea of these gauges. Their general arrangement and manner of working are the same. They differ principally in the manner in which the record-sheets are adjusted:

The float, which moves in a float-box of the kind before described, is suspended by a cord which plays on a grooved wheel called the float-wheel. This is mounted on a steel axle, which is free to revolve in either direction. The cord of the float is kept taut by a counterpoise of weight sufficient to accomplish this end without danger of lifting the float, which remains free to rise or fall with the tide. The counterpoise is suspended by a cord which plays on a smaller wheel clamped to the axis of the float-wheel. To a small drum, also clamped to this axle, is attached the chain which moves the pencil.

The cylinder bearing the record-sheet is so connected with a clock as to make one revolution in any desired time—generally twelve or twenty-four hours. The co-ordinates used in reducing the tidal observations are, of course, *time* and *height of tide*. The *time* is given by the revolving cylinder which moves with the clock. The *height of tide* is given by the recording-pencil in the following manner: At each end of the cylinder an arm supports a pulley. Connecting these two arms is a track, along which travels backward and forward the carriage of the recording-pencil, its motion being parallel to the axis of the cylinder. The chain attached to the drum on the axle of the float-wheel passes over one of the above-mentioned pulleys, and is fastened to one side of the pencil-carriage. To the other side a similar chain is attached, and, after leading through the opposite pulley, a small weight is fastened to it. As the tide ebbs and the float falls the chain is wound on its drum and the pencil is drawn toward one end of the cylinder. As the tide rises the chain is unwound, and the weight attached to the pencil-carriage draws it in the opposite direction. The linear value of the quantities recorded bear to the actual rise and fall of the tide the ratio that the circumference of the drum bears to that of the float-wheel. Suitable scales for the ready conversion of these quantities accompany the gauges.

The preceding applies either to Mr. Avery's "large cylinder gauge" or to "Saxton's three-cylinder gauge." In the arrangement of the record-sheets they differ. In the "large cylinder-gauge" but one cylinder is in use at a time. The record-sheet is passed around this, its edges brought together and fastened. Near each end of the cylinder a line is traced around the drum, and the

circles so formed are divided to half-hours or hours. Any hour-line on the sheet is found by simply drawing a line between the corresponding marks at the ends of the drum. As the tide will never describe the same curve on consecutive days, the sheet may be used through several revolutions of the cylinder; but care should be taken not to let it run so long as to create confusion. These gauges are generally provided with two cylinders. When the one in the gauge is ready for removal, the second one, with a new record-sheet, is placed in position; the first one being taken out to be read at pleasure.



The "three-cylinder gauge" is adapted for continuous record. The record-sheet is wound on the first cylinder at starting, and as the record proceeds it is unrolled from this and rolled on the third one, first passing over the second. It is the second cylinder that is connected with the clock. At the ends of the three cylinders are grooved wheels, and an endless band imparts the motion of

the middle one to the other two. Instead of the graduated circles of the large-cylinder gauge, the middle cylinder is furnished with needle-points in the corresponding positions, the distance between the two sets being somewhat less than the width of the record-sheet. The hours or half-hours are thus pricked into the paper. To guard against error or confusion, the hour corresponding to particular punctures should be written in pencil on the edge of the sheet at least twice a day.

In both forms of gauge the cylinders should be carefully adjusted to the clock at starting and the adjustment occasionally tested.

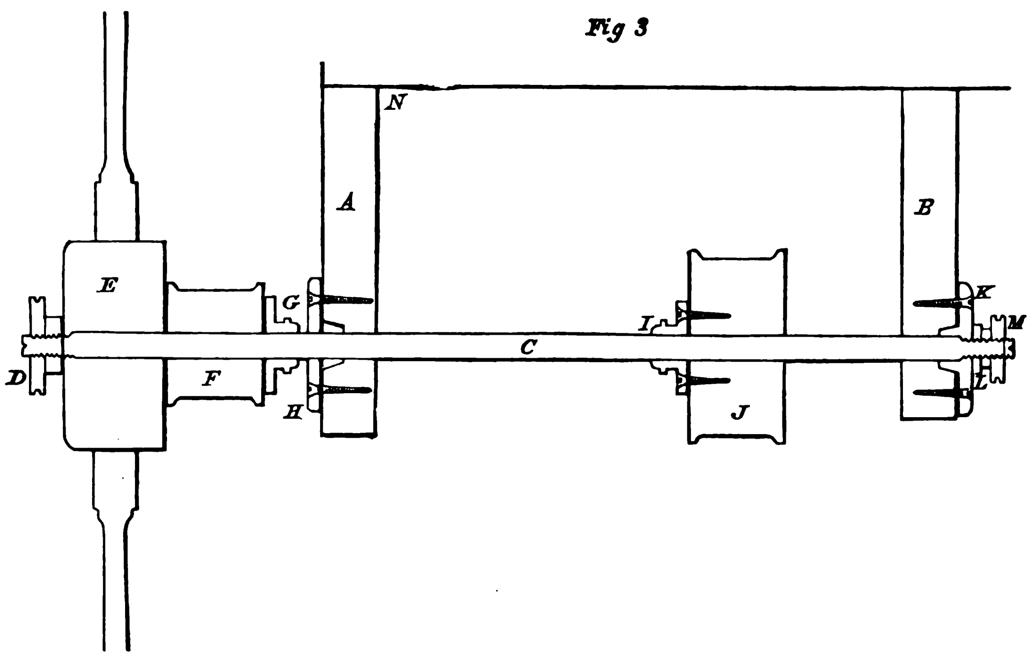
In connection with the self-registering gauges, a staff-gauge should be used to get the relation between the readings of the former and the height of tide. When this relation is well established, it may be applied as a constant to all the readings of the record-sheet.

The following description and accompanying diagrams will give a more detailed account of the construction and manner of working.

A perspective view of one of the large-cylinder gauges, with the principal parts in place, is given on the preceding page.

Details of the construction, represented in the other sketches, will be referred to in the following description of the apparatus:

Fig 3

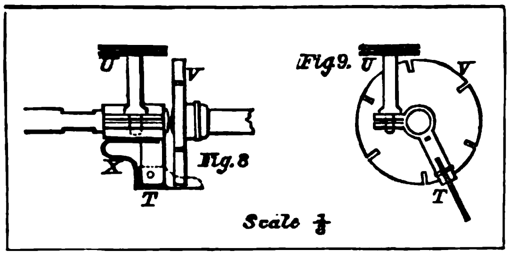


In Fig. 3 are shown A and B, the parts of the frame to which the axle of the gauge is attached. C is the steel axle carrying the large float-wheel E, the pulley F for adjusting the motion of the recording-pencil, and the pulley J for the counterpoise W, and D and M are finger-nuts. G and I are pinned to the axle C. The boxes H and K, in which the axle runs, are secured to the frame, and the washer L secures M from becoming loose while running. E and F admit of adjustment for position and are then clamped by D.

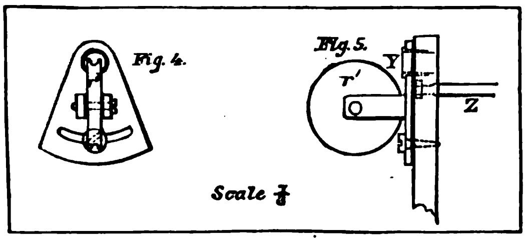
The cylinder that carries the record-paper, is made thus: A steel axle is provided, the clamping end of which is shown in Fig. 8 and Fig. 9. The cylindrical part is made of paper, pasted and wrapped alternately until a thickness of an eighth of an inch is attained. The paper is then dried and fitted with wooden ends, and the brass hubs are fixed with screws and pinned to the axle. The wooden ends are each made of two layers in small sectors overlapping, the grain of the wood running radially.

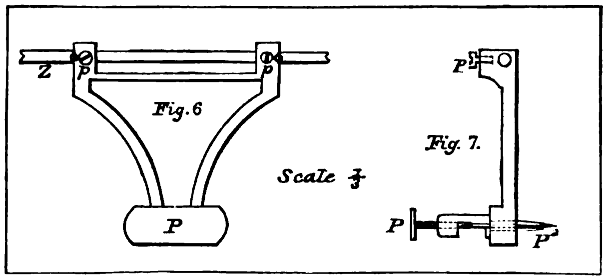
The clamp by which the cylinder is made to move with the clock is shown in Figs. 8 and 9, the

notched wheel V being pinned to an axle of one of the clock-wheels, while T is clamped to the axle



by the milled-head screw U. The clamping-lever is locked into V in Fig. 8, and thrown back in Fig. 9, the spring X being added to keep it in either position as may be desired, and all parts are so disposed and proportioned as to counterbalance each other in any position. The float-line, represented in the figures by a dotted line, is partly wound up on the wheel E, and extends from it down to the float, which rises and falls with the water on which it rests in the float-box. The line is a well-varnished silk cord of the kind used for the best fishing-lines. The pencil-chain of silver, running over the pulley *r* and connecting F and P, is also represented by a dotted line. As F must be suited in size to the average rise and fall of the tides at the place of observation, it is necessary to mount *r*, so that it can be turned to different angles. The mode of doing this is shown



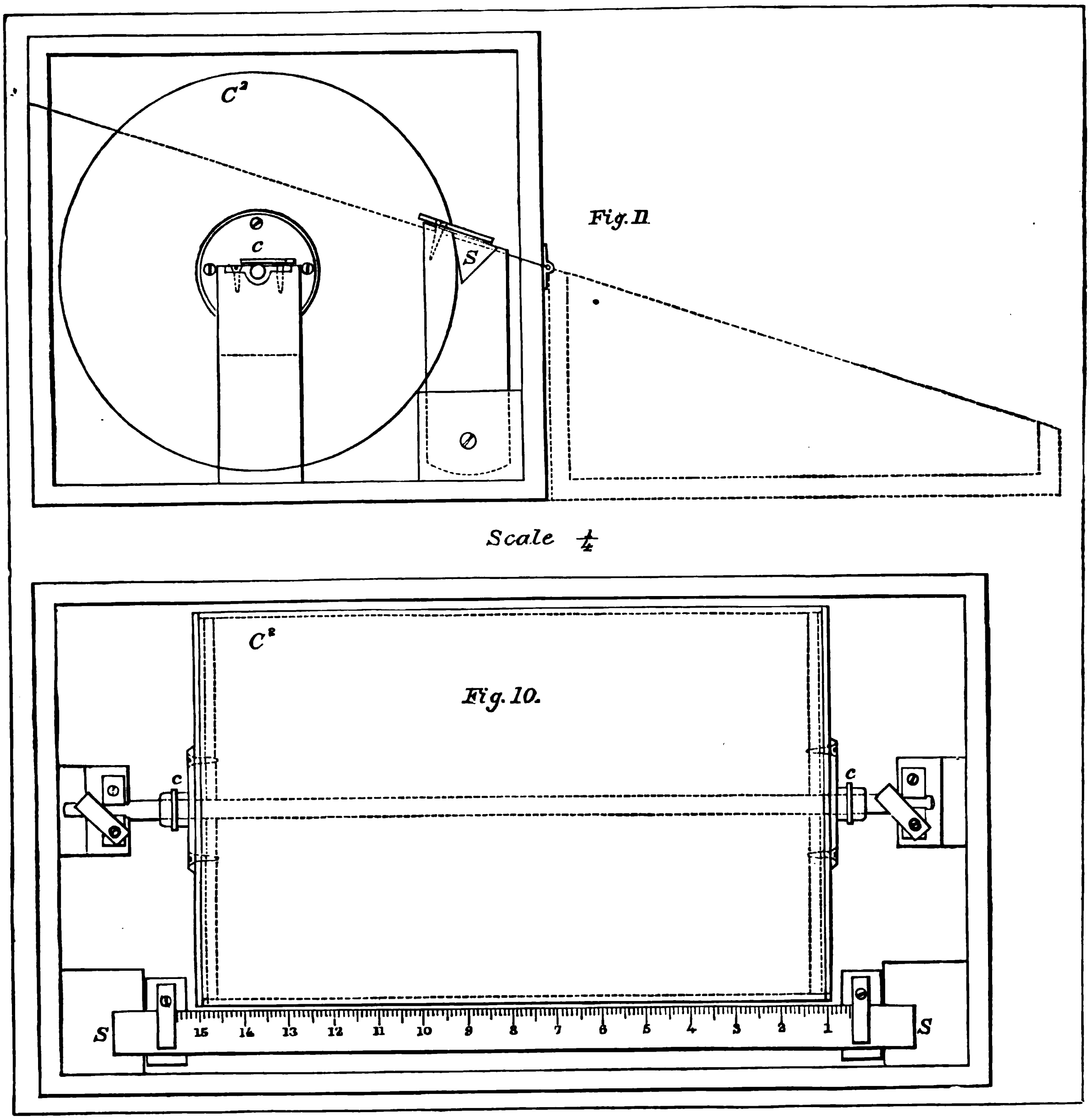


more clearly in Figs. 4 and 5. The form of the pencil-frame is shown in Figs. 6 and 7. Figs. 10 and 11 (see following page) show the reading-box with one of the large cylinders and reading-scale mounted in it for tabulating the ordinates of the tidal curve traced in the gauge. Two of these cylinders are provided so that one can be read in the box while the other is in the gauge. When the cylinder is fixed in the box, and the top put on and fastened by its hooks, it may be carried to any place desired by the handle.

So far, the description applies to Mr. Avery's large cylinder tide-gauge. Mr. Avery has also devised a plan by which the clock is made to move the three rollers of the Saxton gauge so as to make it *continuously* automatic by means of an endless band, as shown in Figs. 12, 13, and 14. He has also applied to it the improved mode of clamping shown in Figs. 8 and 9, and the mode of mounting the wheel and pulleys shown in Fig. 3, and has substituted balance-clocks, moved by weights, for pendulum ones. By these and other minor improvements many of the causes of stoppage and imperfect work have been removed and the instrument rendered very complete.

A, B, and C, in Figs. 12, 13, 14, represent the ends of the rollers, each of which is usually made about 13 inches long and 3½ inches diameter, the middle one B being furnished with a ring of 24 equidistant short steel spurs at each end, a foot apart, to move the paper and prick the half-hour points to read from. A piece of the record-paper about 21 yards in length, enough for a month, is wound upon A at the beginning of each month, and passes over B beneath the impression-roller D, and then under C upon which it is wound up. The dotted circles and line show the rolls of the record-paper on A and C, and its path from one to the other. E, F, and G are the band-wheels, one being placed on the axle of each cylinder, while the endless band connects them all as shown in Fig. 12. F is fixed by screws upon the end of B, which is clamped to the clock and turns round in twelve hours. E and G, therefore, derive their motions from F. The band passes entirely round F, its direction of motion when recording being shown by the arrow above, and its crossing enlarged at L. H is a pulley, hanging beneath in its frame, O, attached to one leg of the frame of the gauge by the bolt P, and drawn down by a weight, W, of about 1½ pounds to keep the band stretched. K and K′ (not shown but placed on the other side of F) are to guide the band. I and J are triangular friction-plates, carried by E and G and sliding on brass plates on the ends of A and C, and the effect of their action is to keep the record-paper stretched as it is drawn off from A and wound up on C.

The relative diameters of E, F, and G are so proportioned as to just do this without unnecessary friction, as the pressure of the friction springs on A and C can be nicely adjusted by the finger-nuts M and N. The washers *m* and *n*, sliding on pins in the axis, are used to prevent the nuts from becoming loose while the gauge is in operation. These gauges work finely, and are to be preferred where the rise and fall of the tides is small and the effects of winds or river-floods large in proportion to the normal tides. It has been found from long trials that in places where the gauges are exposed



to jars, as on many of the wharves occupied by observers, it is best and sometimes necessary to use gauge-clocks moved by weights, but having balance-wheels instead of pendulums. In very quiet and stable positions the pendulum-clocks are preferable. These remarks apply to gauges of either form. The large cylinder-gauges appear to be preferable where the average rise and fall of the tides is much greater than the effects of all disturbing causes.

HOW TO USE A SELF-REGISTERING TIDE-GAUGE.

When a self-registering tide-gauge is used it is done to obtain a correct and continuous record of the height of the tide, so that the height for any hour or minute during the whole period of observation can be easily found therefrom. The mode of doing this will here be given, but, as the gauges differ considerably in their construction, we shall have to suit our remarks more or less to those of the most approved form. We shall assume that if the reader fully understands how to use these he will find no difficulty in learning how to use any other.

Fig. 12

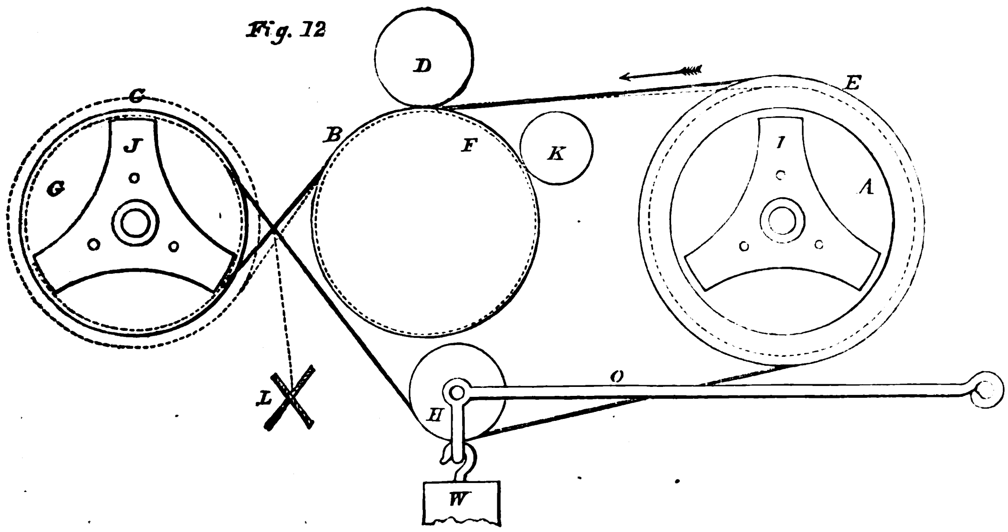


Fig. 13.

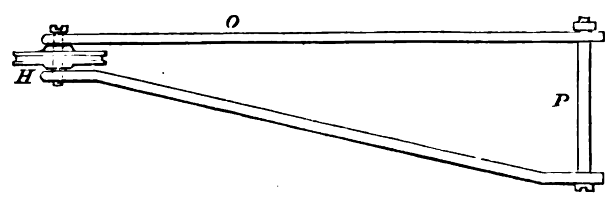
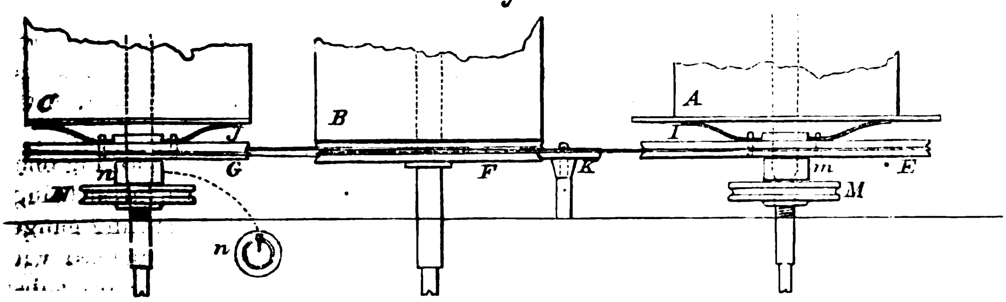


Fig. 14.



Packing up the gauge.—Take off the float and all the weights, and then detach the pendulum, if there be one, carefully lifting it up by the bob to prevent the pendulum-rod, which is often made of well-varnished wood, from being broken or bent, and being very careful not to bend or break its supporting springs. When a balance-clock is used it is sometimes taken off and packed carefully by itself, on account of the more delicate construction of some of its parts. Unscrew the legs from the top part of the frame and take them off. The legs, the pendulum, the float, and the weights are

usually put into a long box by themselves, while the top frame, with the clock attached, is often put as one piece into a large square box. The large wheel may be put into one of these boxes or the other, as is most convenient; but see that the weights and all the loose parts are either tied, braced, or so arranged that they cannot move or get loose. Sometimes all the parts of a gauge are put into a single box. It is important to have everything dry when packed. The covers to the packing-boxes should be put on with screws, so that the instrument can be easily taken out or repacked when not in use or its transportation is required. And the boxes, stuffing, &c., should be carefully preserved for this purpose.

Setting up the gauge.—It will be best not to unpack the gauge until the tide-house is prepared to receive it, and the float-box fixed in its place. A very stable wharf, not subject to jars, is best, and the water should be deep enough to allow the bottom of the tide-gauge to be several feet—at least four—below the lowest tides. The tide-house may be about 5 feet by 8, and high enough to stand in, and if the wharf be solid its floor may project 12 or 18 inches over the water, having a square hole through it for the float-box; but if the wharf rests on piles, or is open underneath, it is better to cut a hole through it for the float-box, as the house will be better supported. If the house is in an exposed place it should be fixed to the wharf with spikes or screws. The float-box has generally been made of pine plank 1½ or 2 inches thick, in the form of a long square tube, having a hole running through it about 6 inches square. It should run up 3 or 4 inches above the floor in the tide-house, and descend well toward the bottom, where it may terminate in a short funnel having a hole at the end of half an inch or a little more in diameter. This shape and mode of setting prevents sediment from accumulating in the box.

Where a self-registering gauge is fitted up for a long series of observations, and it is very desirable to avoid breaks in it, such as arise from accidents and the decay of the wooden parts immersed, it has been found of great advantage to have a round tube 5 or 6 inches in diameter for the float to work in, made of sheet-copper terminating at the bottom in a funnel, with a small hole to admit the water like the wooden box; this is slipped down into the outer wooden box, and has a narrow flange at top where it rests on the wooden box. And sometimes the outer box is covered with sheet-copper, inside and out, to protect it from worms, which, in many places, destroy unprotected wooden boxes in a short time. One great advantage of the inner copper tube is that it is so light that one or two men can readily slip it out and inspect it when necessary or repairs are needed, whereas the outer case generally has to be strongly fixed up, is heavy, and manipulated with difficulty. Another advantage is that when one float-box is used inside of another the water-surface becomes much more quiet than with one only. The outer one also shields the other from injuries.

We are making arrangements to substitute for the above copper tubes others made of sheet-iron covered inside and out with a durable coating of enamel. It is expected that such tubes will be very durable, like the plane tide-meters covered with a porcelain glazing we have been using.

The best outside protection is afforded where a well is built in the wall of a dock or in a stone pier, one or more holes being left at or near the bottom to communicate with the water outside, and it would be well for governments to require one in every navy-yard and large port. The Coast Survey has sometimes used a crib built of logs interlocked at the corners and filled in with stone, a well-hole being left in the middle over which the tide-house was placed.

A staff-gauge or a box-gauge has generally been fitted up near a self-registering one to afford the means for making daily or frequent comparisons, the adjustments of the latter being liable to changes in making repairs. But some recent modifications of the self-registering gauges tend to make them more independent of these auxiliaries, which can, perhaps, be dispensed with by employing more skillful observers, improving the apparatus, and fitting them up more substantially.

When all is ready the tide-gauge may be unpacked and set up, observing to follow the numbers marked at the corners in putting the legs in their places. Then put the great wheel in its place, and the pendulum, if one is used, and hang on the weights. The largest weight drives the clock, a small one of a pound or so is the counterpoise for drawing the pencil-frame and keeping the silver chain stretched, and one of intermediate size is a counterpoise to put on the pulley on the axle of the great wheel under the frame, to keep the float-line stretched. Next suspend the float in its place by the float-line, and see that this is properly wound around the great wheel, and on the right side of it. Hook on the little silver chain that connects the pulley on the axle of the great

wheel with the pencil-frame. The proper length for the float-line must be found by trial, and this will be obtained when the high and low water turns of the curve are traced about equally distant from the opposite sides of the paper. When that length is found the line must be permanently fastened by a knot or by tying it to the rim of the wheel, and any surplus cord may be wound up on the spokes, so as to be out of the way and ready if it be wanted.

MANAGEMENT OF A THREE-ROLLER GAUGE.

A roll of the paper for a month's record is wound very smoothly upon the roller having brass disks on its ends, the end of the roll being first fixed in its clamp. The free end is then passed under the pencil-frame and over the middle roller, the small pressing-roller which rests on the middle one being taken off while the paper is being put on. The paper is then passed under the other roller and fastened in its clamp and wound on enough to make it stay stretched. In the old gauges, small weights were used suspended by cords from spools on the ends of the first and third rollers to keep the paper stretched. In the three-roller gauge, as now made, an endless band passing around three pulleys on the ends of the three principal rollers is so arranged as to keep the paper stretched. This form of gauge we have already described. While putting on or taking off paper, detach the middle roller from the clock by loosening the finger-screw or moving back the lever that makes the connection. When the paper is on, adjust the middle roller, which is furnished with 24 needle-points around each of its ends for pricking the half-hour points, so that when the pencil is drawn to the edge of the paper it will come exactly against one of these needle-points on the roller precisely at the time when the clock points to an hour or half-hour, the clock having been previously set correctly. Once a day the pencil should be moved in the same manner exactly when the clock points to an hour or half-hour to test the agreement of the needle-points with the clock-hands, and the day of the month and hour or half-hour noted on the sheet near the line in pencil. After a sheet is started the adjustment should not be changed, unless it becomes necessary on account of some accident, and then the particulars should be fully noted in place on the sheet. After the pencil has been adjusted to the needle-point as directed, the hands of the clock must not be moved for time-correction without readjusting the pencil until the paper is changed. The roller connected with the clock and also the minute-hand of the clock will generally have a little play, which must be allowed for when setting the pencil to its proper place on the paper, so that the pencil will stand right when the gauge is in motion, the pressure being in one direction. At the beginning and end of each monthly roll, note in pencil the year, month, day of the month, day of the week, hour, and minute of starting or stopping, name of station and observer, and number of gauge and scale, and on the proper sides of the paper "high water" and "low water." Other details common to these forms of gauges with those having large cylinders will be understood from reading the following directions suited to them.

MANAGEMENT OF A LARGE CYLINDER GAUGE.

A completely-furnished gauge of this kind has two recording-cylinders and a reading-box. These cylinders are used alternately, one of them being in use in the gauge, while the other is put into the reading-box and carried to a convenient place for tabulating the readings. If only one cylinder is furnished, the sheet must be removed when full and another substituted, the readings being made on a table or in a suitable frame. To cover one of the cylinders with paper, it is a good way to cut off from one of the long rolls a piece an inch or two longer than is required to reach around the cylinder to allow for the necessary lap to paste to, then lay this piece on a table and take a large towel or other piece of cloth large enough to cover it, and having dipped this in water and wrung it out, lay it down upon the paper for a minute or so to dampen it, then put the paper around the cylinder quickly, and carefully adjust it to the right place by seeing that it lies equally between the black lines turned round the ends of the cylinder, and that the lap is made the right way for the pencil to slide over the pasted edge when the gauge is working, and then tie an elastic string around the middle of the cylinder over the paper to keep it in its place; observe also that the place of joining comes just before the hour marked 0^h on the edge of the cylinder, so that when the sheet is taken off, the division may be made at the lapped edge and the observations for each day will be

unbroken. Then it may be well, especially in very drying weather, to wrap the damp cloth around the cylinder over the paper for a minute or so, when the paper may be drawn to fit tightly and fixed in its place by a little mucilage put under the free edge in five or six places with a brush and pressing it down. The paper must not be made too damp, for then it may burst when it dries. It should be merely damp enough to make it fit tightly so that it cannot slip while in use. A little experience will enable one to do it well. An elastic band may be put around one or both ends of the cylinder over the edges of the paper for greater security. Having fixed the paper on the cylinder, the next thing is to transfer the divisions or hour-marks and their numbers from the ends of the cylinder to the edges of the paper, so that the hours may be preserved after the paper has been removed. This can be done conveniently while the cylinder is lying in the reading-box. If the gauge has but one cylinder, it can be done while this rests in its place in the gauge. When the cylinder is put into the gauge a circle must be turned around each end of it on the paper by moving the pencil-frame first to one end of the rod it slides on, and, while held there, turning the cylinder round, marking with the pencil on the paper as it turns, and then in the same way at the other end of the cylinder. These lines determine the extreme reading-points, and insure uniformity in reading the sheets. The next thing is to clamp the cylinder to the clock so that it may be properly driven by it. To do this, loosen the clamping-screw and move the little clamping-lever into its place on the disk that projects from the back of the clock; then turn the cylinder till the hour the recording-pencil stands on agrees with that shown by the driving-clock, having previously set this to the true time, then turn the screw and clamp the cylinder to the clock. Observe that our custom is to make the day commence at midnight, so that midnight is 0^h, 1 a. m. is 1^h, noon is 12^h, 1 p. m. is 13^h, 11 p. m. is 23^h, &c. A cylinder may be kept running for several days in most places before the other is substituted or the sheet taken off. The length of time, however, must depend on the convenience of the person in charge, the nature of the tides at the place of observation, and the importance of obtaining such records as will be free from all confusion; but it will be best to change so often that the records can at any time be conveniently read. To facilitate the reading, it will be well for the observer, when he visits the gauge, or at least once or twice a day, to mark the day of the month on the line behind the pencil. The year, the month, and the days of the month and week, when the record begins and ends, must also be marked on every sheet; also the high and low water sides of the sheet; also the name of the station, the observer's name, the number of the gauge, and the scale to which it is working.

TABULATING HIGH AND LOW WATERS.

When a sheet is filled, it should be placed in the reading-box, and without being exposed to the sun, or in too dry a place, which would probably cause it to shrink in dimensions, it should be carried to a convenient place for tabulating, which should be attended to soon. Mark by pencil-dots on the curve the places where the *high* and *low* waters occur. Then read off the high and low waters, always reckoning from the marginal circle on the low-water side, which should agree with some particular division of the triangular scale used for reading, and write them in their proper places on the *forms* used for this kind of tabulating; also write the time of each to the nearest minute. For getting the time easily it may be found most convenient to draw the hour-lines preceding and following each of the points to be read entirely across the sheet, and use a small proportional scale for finding the minutes in reading. The triangular scale used in the box for reading heights may be moved a little endwise for adjustment, but should be set and clamped so that the marginal line on the low-water side of the paper may always be on the same division of it, or, what will be equivalent, see that this reading-scale always lies precisely in the same place and is well clamped to prevent motion endwise. No change should be made in this setting unless required by some new adjustment of the gauge, and to preserve the relation of the readings to the bench-mark. The scale may be pressed close to the cylinder while reading. A staff or box gauge or tape-line is always put up near or in connection with a self-registering gauge, so that the observer can compare the height read on this with that given by the scale, and this he is expected to do generally twice a day, noting the time in place on the record. These comparisons are copied into their places on the *form* for high and low waters, and the average relation of the scale and other gauge is found

for each month or so. This relation enables the computer to reduce all parts of a series of observations to uniformity, as it shows what correction to apply to the scale-readings to do it, and the observer is generally required to fill out the columns for corrected time and height.

Comparative readings are most valuable when made at or near high or low waters, and most convenient to use when made at the hour or half-hour marks and estimated if possible to hundredths of feet. The use of these comparative readings is to guard against the irregularities and uncertainties which are liable to occur, as the self-registering gauge is exposed to various accidents, such as the breaking and repair of the pencil-chain or float-line, by which the relation of its record to the bench-mark may be changed.

TABULATING HOURLY READINGS.

The high and low water readings will suffice for computing approximately certain values which are much used, such as the average lunitidal intervals, average rise and fall of tides, and the relations of spring and neap tides. But for making a more complete investigation of the laws of the tides and of the various changes to which they are subject it is best to tabulate the hourly values of the ordinates of the curve traced by the gauge. A convenient *form* for doing this has been provided. These values being read while the cylinder or sheet is still in the reading-box or its substitute, and with the same scale that has been used for reading the high and low waters and in a similar way, it is not necessary to describe the process more fully here. Blank forms, to be filled up by the observer, are furnished from the Coast Survey Office, with ample instructions for tabulating high and low waters, and also the hourly readings.

SCALES OF HEIGHT.

Three small pulleys are generally furnished with a gauge, especially when the rise and fall of the tides at the locality is only roughly known. Then, for example, with one it would work to a scale of $\frac{1}{5}$; with the one sent in place it works to a scale of $\frac{1}{7}$; and with the other it would work to a scale of $\frac{1}{10}$. The relative circumferences of the pulley and the large wheel determine the scale. The pulleys furnished are suited, as well as can be predetermined, to the place of observation; but three are generally sent, that a change may be made if found necessary. The triangular-reading scale will answer for either of these, as its edges are graduated differently; but the observer should be careful to read always with the edge that corresponds to the pulley he is using. Five of the principal divisions of the $\frac{1}{5}$ scale is equal to a foot; 7 of these divisions of the $\frac{1}{7}$ scale is equal to a foot; and 10 of the $\frac{1}{10}$ scale is equal to a foot, and so on for other scales. The one found on trial to be best suited to the range of the tides at the place of observation should be used there; but if any change is made, it must be conspicuously noted down among the observations on the sheet in use at the time.

TIME.

The gauge-clock should be kept as nearly as possible to *mean solar time*, and it should be compared often with some standard time-keeper, or, when that is impracticable, with the sun by means of a meridian-mark, sun-dial, or dipleidoscope established for the purpose, and the result noted on the sheet or accompanying records, applying the equation of time taken from an almanac or suitable table. It is better to have the clock set to run a very little too fast than too slow, as it can then be put to the true time by merely stopping it a few moments without deranging the relation to the recording parts; whereas if it run too slowly, the hands would have to be advanced, and this would necessitate a readjustment of the pencil on the sheet.

PRECAUTIONS.

Full and clear notes must be made on the sheet or accompanying record of everything done, every readjustment or time-correction, every accident or breakage or repair, every stoppage, with its cause and duration, every comparison of time or height.

The greatest care should be taken to obtain a continuous unbroken record, and for this reason it is best that the observer visit the gauge at least two or three times a day, as early and as late

in the day as practicable, and, if convenient, near noon. He should keep a close watch on all the details, and clean and oil the working parts as often as they need it, especially the rod on which the pencil-frame slides. Very little oil should be used, however, as too much is needless and filthy. If it become necessary to interrupt the record to make changes or repairs, choose a time intermediate between high and low waters, as it is very desirable to have the parts near high and low waters unbroken.

Should a protracted stoppage be uavoidable, the observer should observe on the staff or auxiliary gauge all the high and low waters, and as many hourly readings as he can. In observing high and low waters on the auxiliary gauge he should begin some minutes before the time and continue a while after, to be sure that the tide has turned during his observations. Covers have been furnished with each gauge for the clock and cylinders, and these should be kept on, except when it is necessary to inspect the work or the apparatus. They protect from dust, spray, and dampness. The cover on the clock can be easily removed after turning out the brass screws that hold it. A place is provided on the clock side of the frame or inside for the winding-key and all the tools for turning the various screws, and they should be kept there, that they may be readily found when wanted. Probably the best way to take a sheet off the cylinder will be to cut very lightly with a sharp penknife along at the edge that laps over, being very careful to cut no deeper than is necessary to divide the paper, for the cylinder, being made of paper, might be injured by deep cutting. The sheets should be carefully rolled up for preservation, and sent monthly to the Coast Survey Office, or assigned place of preservation with fair copies of the tabulated readings for high and low waters and staff comparisons and tabulated hourly readings, as these cannot be so accurately made afterward, owing to the shrinking of the paper. The sheet, however, should not be sent by the same mail as the tabulated readings derived from them, the latter being sent first. This rule is to guard against the loss of observations by mail-accidents. It is well, especially where there is no meteorological observatory in the neighborhood, to keep up a regular series of meteorological observations at every permanent tidal station where a self-registering tide-gauge is used, particularly of observations with thermometers and barometer, and of the direction and force of the wind, amount of rain, &c., as the tides are often greatly influenced by meteorological conditions. These meteorological observations may be arranged in tables on blank forms sent from the office to be filled up by the observer, and sent back monthly with the tidal observations, or they may be kept in books ruled for the purpose and sent at designated times.

APPENDIX No. 9.

CHANGES IN THE HARBOR OF PLYMOUTH, MASS.

BOSTON, *May* 1, 1876.

DEAR SIR: I desire to call your attention to evidences of important physical changes in the harbor of Plymouth, which are furnished by comparisons of Champlain's sketch (1605) and Blaskowitz's survey (1774), with the most recent chart of the Coast Survey.

The first of these documents is found in the published works of Champlain; the second is before me in the original manuscript, bearing the autograph of the author, with his official title, "Deputy Surveyor for North America."*

Champlain.—The sketch of Plymouth, under the name of "Port St. Louis," may be found in Chapter VIII of Champlain's Voyages. The copy appended, from which conventional signs, &c., irrelevant to our present inquiry have been omitted, is from the recent Quebec edition.† From the text it appears that the little vessel bearing Champlain (who was not the commander) ran into this "*cu de sac*" to wait for a fair wind to continue the voyage on the 18th of July, 1605, and remained there only one day. The positions are given upon the sketch of two anchorages, one in the middle of the roadstead, which we may assume was the first occupied, the other near the point of Long Beach.‡ They were tempted to leave their first anchorage by the hope of going in their vessel into the "river," to which they were invited by the Indians; but they found the water too shallow, "it being low tide," and again let go their anchor.§ This vessel drew less than five feet, and the sounding given on Champlain's sketch indicating the end of the course is one fathom, from which we learn that his soundings are reduced to low water. Champlain went on shore and reconnoitered the river and found it only an arm of the sea. He describes the bay as a place about one league in circuit, evidently meaning the "*cu de sac*" into which the vessel ran for an anchorage, and not the entire water-space. It is this "*cu de sac*" that he sounded out, and, although he does not represent Brown's Bank, the limits of his soundings indicate that the bank was there, but that he did not know that any ship-channel lay between this bank and the Gurnet or Saquish. If this bank had been as elevated as it now is, so as to run dry at low water, he would probably have represented it on his sketch and have guessed that the great entrance channel to interior waters lay beyond. In the text he refers to the Gurnet as covered with wood, principally pines, and as "attached to a pretty long coast of sand dunes." He then speaks of two "*islets in the said bay*" (evidently Saquish and Clark's Island), "*which are not seen unless one is within, around which the sea runs nearly dry at low tide.*"

Champlain's map is in the main a wretched eye-sketch, one of the worst which appears in his narrative. He evidently did not think the anchorage a valuable one. He had gone in on the wrong side of Brown's Bank and just missed the discovery of a most excellent harbor. Assuming nothing for this map beyond that which would impress us in the most ordinary sailor's sketch, we still must admit that there are points of value in it. He had two instruments, a compass and

* This manuscript map of 1774 is the property of Mrs. Mary Winslow Russell, grand-niece of the Edward Winslow, jr., to whom the map (as its legend states) was presented by the author. This map has never been published; but Dr. Nathan Hayward, Mrs. Russell's nephew, for his own amusement and to gratify a private circle of friends, made, some ten years ago, a few lithograph copies, one of which I send with this report. This lithograph is generally faithful, but it omits the line of soundings in the main ship-channel, which happens, from our point of view, to be the most important part of the testimony. I therefore send, in addition, a copy of the original manuscript, from which I omit the strictly topographical details, although they are admirably executed upon the original with the pen and brush.

† *Œuvres de Champlain publiées sous le patronage de L'Université Laval, par L'Abbé C.-H. Laverdière, M. A.*, 1870.

‡ The vessel pictured in the roadstead is simply a conventional sign of proper anchorage.

§ On July 18, 1605, low water must have fallen as late as 6 p. m., if Champlain's dates are, as presumed, Gregorian.

a lead line, and he evidently designed to represent the position of the anchorage in its relations to the two entrance headlands and to Long Point. With his compass, corrected for the variation determined by him at Malle Barre on the previous voyage, we find the tangents from the conventional vessel to the entrance headlands (at the shore-lines) to be N. by E. ½ E. and ESE., while the point of Long Beach bears NW. (true). We also observe that a considerable portion of Clark's Island is open to the westward of Saquish. With these bearings and ranges, we plot the vessel upon our Coast Survey map, and find it lying at least two miles from Rocky Point and over three from Gurnet Point.

These two points have no doubt washed away somewhat; but with every possible allowance for waste, we cannot conclude, from the data thus far referred to, that the anchorage-place was less than 1¾ statute miles from the outer chord of the entrance. In the sketch, however, Champlain makes the vessel lie about midway between the outer chord and Long Beach, which would reduce the distance we have just given to 1¼ miles. Having satisfied ourselves that the vessel lay from 1¼ to 1¾ miles from the entrance, let us examine the soundings which he has grouped about this vessel and extended seaward in the sketch. We find that, in the circle of a half mile diameter about the vessel, there was an average of 7½ fathoms—the extremes being 5 fathoms on the inside and 9 fathoms on the outside. The same circle on the Coast Survey chart shows a mean of about 3 fathoms and nothing greater than 4 fathoms in 1853. Again, we find that from his anchorage nearly to the chord of the bay Champlain made numerous soundings, showing that a pathway about a half mile wide could be followed out of the bay with an average depth of 9 fathoms of water, and that when still quite within the tangent chord of the bay, so as to be in the narrowest part of the entrance, there were 10 fathoms where there are now less than 6. You will observe that he gives four soundings of 10 fathoms *as if to make sure to represent the entrance depth of this "cu de sac."* In the subjoined table a comparison is presented of his soundings with those of the Coast Survey in 1853.*

Distance from entrance in statute miles.	Depth in fathoms.		Loss of depth.	Remarks.
	1605.	1853.		
0	Not given.	5¼	....	Outer tangent line from Gurnet to Rocky Point.
0.25	10	5¼	4¾	Between entrance headlands.
0.50	9	4½	4½	
0.75	9	4½	4½	
1.00	8	5	3	
1.25	7	3½	3½	
1.50	5	3½	1½	

It is safe to conclude from the above that the deeper portion of the cove or bay between Brown's Bank and Rocky Point has received an enormous deposit since the visit of Champlain.

As well as we can judge from the sketch, the depth found near the point of Long Beach was about the same in 1605 as it now is, although there can be no doubt that alterations of Long Beach itself have been in progress since that time.

There is no evidence of any general emergence of the New England coast indicated by any comparisons that I have made of Champlain's maps with those of the Coast Survey. Salt-marshes indicated by Champlain in his map of Saco, Me., are marshes still, and the depths over the rocky bottom of Gloucester, and even in some of the lagoons of Cape Cod, remain the same. The Old Colony records of very early dates abound in references to the salt-marshes of Plymouth, Duxbury, and Marshfield, which were peculiarly valuable in a country where the uplands were not yet cleared. We have taken pains to investigate a little this question of emergence, because a very able geologist has asserted that the coast of the "Gulf of Maine" rises from one to three feet in a century.

Blaskowitz (1774).—In its topographical features the original plotting made by Blaskowitz from his survey of Plymouth is remarkable for accuracy and beauty. It is deficient in soundings, but

*Our latest published chart bears date of 1875; but the most recent soundings it contains of the entrance to Plymouth are those of 1853, made by Lieut. M. Woodhull.

the depths in the principal channel-ways are given and seem to be designed to be those of the best water at low tide. The depths in the channel through the Cow Yard and along the main ship-channel past Saquish Head are represented much less in 1774 than upon our latest Coast Survey chart. It is barely possible that the completion of the cordon of dunes connecting Saquish with the Gurnet (which has been effected since the Blaskowitz survey), and the closing of openings through the beach above and below Rousses Hummocks, may have caused more water to flow in and out of the channels we have named, and induced a greater depth of water. But we should be timid of conclusions relative to *deepening*, because our Coast Survey soundings are so much more numerous than those upon the old map, that the greatest depressions of the channel-bed are more likely to have been reached by us than by Blaskowitz. When shoaling, instead of deepening, is indicated by the comparison of old maps with our own, we may safely conclude that a change has occurred, and this is the case presented in the lower part of the main ship-channel between Saquish and the sea, to which we shall now refer.

The following table shows the comparison of depths in the lower reach of the main ship-channel:

Distance in statute miles.	Depth in fathoms.		Loss of depth.	Remarks.
	1774.	1853.		
1.0	6	4½	1½	One mile westward from tangent line joining Outer Cliff of Gurnet with Rocky Point.
0.80	7	4½	2½	
0.60	8	4½	3½	
0.44	9	4½	4½	
0.25	9	4½	4½	
0.00	10	4½	5½	On tangent line joining Outer Cliff of Gurnet and Rocky Point.
0.20	10	5¾	4¼	Outside of line above mentioned.

GENERAL CONCLUSIONS AND REMARKS.

1st. Champlain entered the roadstead of Plymouth, in 1605, with 10 fathoms of water where there is now less than 6; and Blaskowitz, in 1774, ran into the main ship-channel of Plymouth with 10 fathoms where there are now less than 5.

2d. Champlain, in 1605, found about 4 fathoms more water in the deeper portion of the roadstead than now exists; and Blaskowitz, in 1774, found about 4 fathoms more water, for a distance of a mile, in the outer portion of the main channel than now exists.

It would be rash to conclude that the agreement of these diminutions of depth indicates that the entire change has occurred during the last century; but we drop this hint for what it is worth.

Along the western coast of Cape Cod Bay there are several fiords similar to Plymouth, but of less extent, that have been more nearly filled up with the sands of the coast. There are many thousand acres of salt-meadow in Scituate and Marshfield which are evidently composed of silt from the outside coast where the high glacial bluffs are falling a prey to the dash of the sea, but the headlands at the entrance to Plymouth are now defended by the bowlders that lie at their feet, so that they yield very slowly.

The Gurnet headland has diminished very little since 1774, and the distance from it to Rocky Point has remained about the same.

We have generally regarded the waves as the primary agents for the supply of the material filling up the re-entrant angles of our coast, not only in their direct action upon the glacial cliffs, but also in their transporting power when they drive diagonally upon the shore; but in Cape Cod Bay there is a curious action of the currents that we must not ignore. In the report of the advisory council of the joint committee of the Massachusetts legislature, on the Cape Cod ship-canal (1860), it is stated that the tidal party in Cape Cod Bay discovered a coastwise current which—

> Gave peculiar interest to the observations. This current sweeps along the western shore of the bay, pursuing a northwardly course; it is feeble at the outlet of the canal, but it gathers strength farther north where, according to the observations, it slackened only for about two hours at the time of most rapid rise of tide. The most singular feature, perhaps, of this coast-current that fell under the observer's notice was its very low temperature (in summer).

The next year after this report of the advisory council was made, the same party of Coast Survey observers made further investigations upon this stream. A station was occupied only about four miles southeast of Rocky Point (the southern headland of Plymouth), and there the northerly movement was found to be about a half mile per hour at the surface and but little less than this near the bottom, 84 feet below, a velocity quite equal to the rolling of sand.

3d. The material which has accumulated in the entrance to the main ship-channel of Plymouth, and in the "*cu de sac*" below Brown's Bank, has been brought along shore from the northward by storm seas, and has been swept from the southward over the bed of Barnstable Bay by a current.

Very respectfully, yours,

HENRY MITCHELL,
United States Coast Survey.

CARLILE P. PATTERSON,
Superintendent United States Coast Survey, Washington, D. C.

APPENDIX No. 10.

REPORT UPON THE PHYSICAL SURVEY OF NEW YORK HARBOR, 1876.

There have been made, during the progress of the physical surveys, several reports upon practical points to which our data was applicable, but until now we have not felt able to make a general exhibit of our results. The incidental reports referred to will not be repeated in this, and we shall, therefore, mention them by title in the order of their dates.

"Method of Levelling in Tidal Rivers." Appendix No. 11. Annual Report of Coast Survey for 1870.

"Report on Buttermilk Channel and Jersey Flats," published by the New York Commissioners of Pilots, 1871.

"The Harbor of New York: its Condition May, 1873." Appendix No. 8. Coast Survey Report, 1871, and published also by the New York Chamber of Commerce as a special document May, 1873, and again in the Annual Report of the Chamber in the following year.

"The Middle Ground Shoal, New York Harbor." Appendix No. 16. Coast Survey Report, 1872.

"Note concerning Changes in the Submerged Contours off Sandy Hook." Appendix No. 10. Coast Survey Report, 1873.

The soundings that have been taken from time to time by the party of physical hydrography under my charge have led to modifications of the chart of New York Harbor; but where these modifications have been slight and unassociated with any observed change in physical conditions elsewhere, the chart has been simply corrected at the office without comment.

It is especially the currents of the harbor and their laws that have been my study, and it is to place the results numerically upon record that this report is prepared. The tables appended do not include the data used in previous reports to any considerable extent, because, in the general system designed to be here exhibited, local details are purposely omitted.

The work upon currents has been extended over the upper harbor from the Narrows to Guttenberg, on the Hudson, and to Astoria, on the East River. It has necessarily occupied several years, and the field-work has been executed only in summer and autumn. There are probably defects in the grouping of the results consequent upon the want of continuity in the operations, but it is hoped that these are nowhere so great as to impair their value in relation to the location of harbor-lines or other measures for protecting the harbor from undue encroachments. Our work has been more or less intimately connected with the proceedings of the United States commission on the pier-lines of Brooklyn, especially in the East River, where it has been associated with somewhat similar studies by General John Newton, United States Engineers, who, with yourself and General A. A. Humphreys, compose said commission.

The general purpose reflected in the tables accompanying this report is a comparison between the form of the channel and the order of the forces active within it. The profile of the section, the transverse curve of velocity, and the balance-points of both area and volume form the elements upon which the study must rest. I premise that if the bed of the channel were alluvial, the form of the section should correspond to the transverse curve of velocities of current (or the work they represent); in other words, that the channel is molded by the stream. Conversely, if the channel-bed were rocky, it should subordinate the curve of velocities in more or less degree, so as to make the form of the flow take somewhat the form of the channel.* In New York Harbor the channel-beds are composite in character, being in part recent deposit and in part original firm material.

* As long ago as 1865 it was ascertained which current, flood or ebb, controlled the form of the main channel off South Boston flats by comparisons of this kind, and one need but glance at the diagram attached to the "Tenth Report of the United States Commission on Boston Harbor" to be satisfied with the correctness and value of this method. At the time the Boston experiments were made it was a matter of doubt whether it was proper to employ the first power of the velocities, or the second; the latter seeming more logical since *work* was represented. I used the first

It is evident that the channels as they now exist are not the product of the scour of tide-water, but this scour nevertheless maintains them. There can be no doubt that in general the basins and avenues of New York Harbor antedate the action of rivers and tides of the present order, but these more recent forces have been long busy in removing salients and filling sheltered angles, so that the *tendency* of things is toward a form of section that shall be the perfect mould of the belt of effective forces within it, *i. e.*, suppose that 0.50 feet per second were the limit below which no scour would occur, the filling and excavating will continue till the stream sweeps every part of its bed with this velocity of current.

It is a part of the plan to go through this entire set of observations, and determine the coefficients required to place the curves of velocity in best conformity with the profile of section, both for flood and for ebb. Hoping to be able by contrasting alluvial with rocky sections, to indicate where changes of shore-line would be harmless or even beneficial, and where such changes have been prejudicial, I need not make any further apology for withholding *derived* data, since you are personally familiar with the labor, often misapplied, which such studies involve on the way to success. It will be an advantage to have these tables placed in print, not only because of their direct practical usefulness in projects that constantly arise, but because they will be then in convenient form for studies leading to general rules. I shall proceed to describe the tables and the manner of their compilation in detail.

For the Hudson and for East River I regarded the surface-curve of velocities as typical for all depths—an assumption that seemed warrantable from numerous observations made below the surface—and this surface-curve was reduced to the mean by applying a factor determined in the following manner: At a section off Wall street in the East River, and at another section off Forty-second street in the Hudson, continuous observations were made from shore to shore through an entire tide, and from top to bottom, at central stations. In this way we actually gauged the stream in each case during an entire ebb and during an entire flood, and obtained for each river and tide a *standard volume of discharge* applicable to other sections in the neighborhood. In each of these other sections in the neighborhood we observed only the surface velocities and the depths across the stream; then, by comparison with the standard volume, determined the local factor which should reduce the transverse curve to the same denomination as that at the standard section. In the Hudson, I have preserved thus far the same standard volume, but in the East River I modified it on discovering that the discharge increased as we went eastward from our gauging-place at Wall-street ferry and through the Blackwell's Island channels. One may easily see how this may occur. Taking, for instance, the simpler case of a short arm of the sea closed at one end, the tidal volume passing through the sections increases as we go down toward the sea, both for flood and ebb, because the space behind, covered by tide-water, increases. As the East River was open at both ends, I was for some time doubtful in which direction to expect this increase, or whether the ebb and the flood would be similarly affected. It turned out that the volumes both for flood and ebb increased going eastward from our standard section off Wall street toward Hell Gate, indicating that the East River is to be treated as if it were the only mouth of New York Harbor, and that the words "flood" and "ebb" as popularly applied are transposed in part.

The standard volumes used for the East River, from Wall street to Blackwell's Island, were

power, and now use the expression $\phi v + \phi_1 \sin a$, in which v = velocity, ϕ and ϕ_1 coefficients, and $\sin a$, the serpentine curve for the entire circle. The second coefficient is that for resistance of bends. I found, by comparison of the profiles of the cross-section in the Lower Mississippi River with the transverse curve of velocity, that it was necessary to introduce the serpentine (from shore to shore) to make the two conform. At the same high stage of the river, the first coefficient ϕ remains constant whether the section examined be the main stream or one of the small passes; the other coefficient varies with the radius of curvature. If we have not velocities, but study only profiles of section, the following expressions seem to develop the transverse curve of depths: $X = \frac{W}{2} \sin a$ and $\gamma = \frac{m}{2} \cos a + \zeta \sin 2a$, in which W = width, m = minor axis of an ellipse, a = central angle of the ellipse, and ζ = coefficient varying with the radius of curvature of the stream. With discharge constant, the ellipse remains the same; *i. e.*, $X = \frac{W}{2} \sin a$ and $\gamma = \frac{m}{2} \cos a$ remain constant. By adding to the value of γ, a third element, viz, $\zeta_1 \cos 4a$, a still closer conformity is obtained at a considerable bend.

One object in adding this long foot-note has been to show the direction of our studies and to indicate the complexity which the case of a tidal stream offers at present.

974,266,000 on flood and 964,900,000 on ebb. In Blackwell's Island channels we used 1,085,383,000 on flood, and 1,076,017,000 on ebb.

For the bay below Governor's Island, where there is a counter-current on the ebb at a considerable distance below the surface during the low-water season, we corrected our surface-curve so as to represent mean values by the proportional rise or fall on the Governor's Island gauge during the hour of maximum velocity.

That the method of computation may be more fully understood I give here the details of the work upon Section XXXVI in the Hudson at Sixty-fifth street. Here the distance from shore to shore is 4,208 feet, and in this distance five current-stations were occupied during the strength of the flood and during the strength of the ebb, and close soundings were made all the way across.

Our first step in computation was to plot on profile-paper the observations at the five stations for the same hour of maximum drift. In this plotting, the distances from shore were made the abscissæ and the velocities of current the ordinates. A smooth curve was then drawn with free-hand through the extremities or the ordinates terminating at the shore or wharf-front.* This curve was then adopted as the result of observation and equidistant ordinates were taken out and placed in a table of the subjoined form (A):

SECTION XXXVI.—TABLE A.

Locality: Hudson River, off Sixty-fifth street. Date, September 3, 1875. Standard volumes: Flood, 1,230,610,907; ebb, 2,009,004,765.

Distance from—	FLOOD.				EBB.			
	Maximum velocity.		Mean depth for every 100 feet at standard plane of maximum velocity.	Volumes. (Observed.)	Maximum velocity.		Mean depth for every 100 feet at standard plane of maximum velocity.	Volumes. (Observed.)
	Observed.	Mean for every 100 feet.			Observed.	Mean for every 100 feet.		
0	0.70				1.10			
		0.85	22.9	11,827,000		1.25	19.2	14,582,000
100	1.00				1.40			
		1.10	25.4	16,976,000		1.50	21.7	19,777,000
200	1.20				1.60			
300	......	......	......	......	......	......	......	......
4,000	1.10				0.90			
		0.85	6.1	3,150,000		0.70	2.4	1,021,000
4,100	0.60				0.50			
		0.35	4.6	978,000		0.30	0.9	164,000
4,200	0.10				0.10			
	Total volume			1,702,958,000	Total volume			1,849,724,000

Factor for reduction of *flood* velocities, 0.72; for *ebb*, 1.09.

NOTE.—The standard planes are 4 feet for flood and 0.3 feet for ebb above the plane of mean low water.

In the column of "mean depth" of Table A were placed the soundings reduced to "standard plane"—that on which the maximum velocity occurs during an ordinary tide. The next step in the work was to compute what would have been the volumes passing through the section had the observed velocities been those for all depths. This done, the volumes of flood and ebb respectively were summed up, and by division with standard volume the factors were determined which, applied to the observed velocities, gave the entries for the final table (which appears among those appended to this report) as those which would have been obtained directly if the observations had all been made for all depths during an average tide. In this way it was designed that all the appended tables should have the purport of simultaneous work under average conditions and mean for all depths.

In each of the final tables you will observe two derived data denominated, respectively, "mid-

* Instead of a free-hand curve I should now (since experience on the Mississippi River computations) compute the ellipse best fitting these five (or seven, counting shores as zero) observed velocities reduced to the scale of depths.

area" and "mid-volume." The first of these is the distance from the origin at which a vertical would divide in halves the area of the section, and the second of these is the distance from the origin at which a vertical would divide the passing volumes into two equal parts. As these two data do not appear in any previous work of this kind, a brief explanation of their use may be properly inserted here. They are particularly important as guides in the allotment of privileges of encroachment from either shore, and one may be used to the exclusion of the other in extreme cases which we shall name.

1st. Where the avenue serves no important purpose as a channel of discharge for tides or river-floods, "*mid-area*" would be the natural point toward which the owners on either shore might equally advance to that extent which would not interfere with navigation.

2d. Where the capacity of the avenue must be maintained principally because of the movement of water through it—liable, if too much contracted, to overflow the banks, excavate the bottom unduly, or interfere with the maneuvering of vessels—"*mid-volume*" would properly be the natural point toward which shore-owners might be suffered equally to advance a limited distance.

In the first case stated above, where "*mid-area*" is exclusively used, it would seem unjust to regard depths below the possible draught of ships, and, therefore, in computing this element, the space below this draught might properly be left out.

Instances may occur where (at a bend, for instance) "*mid-volume*" is so far from "*mid-area*," or both so inconveniently near one shore, that, with the hope of straightening the stream, the owner on the concave side might be encouraged to advance at the expense of what would otherwise be the privilege of the opposite owner. But instances like this present exceptional cases, to be entertained as they appear on wider premises than those we are now dealing with.

The computations, of which the annexed tables are but a *résumé*, were made by Assistant H. L. Marindin, Mr. John B. Weir, Mr. Frank W. Ring, and myself. To the first two belongs the principal credit of the field-work, which was executed in careful accord with your instructions and my advice.

Respectfully submitted.

HENRY MITCHELL,
United States Coast Survey.

CARLILE P. PATTERSON,
Superintendent United States Coast Survey, Washington, D. C.

Position of origins and termini of sections examined in 1872–'73–'74–'75.

Number of section.	West end.		East end.		Remarks.	
	Latitude.	Longitude.	Latitude.	Longitude.		
	° ′ ″	° ′ ″	° ′ ″	° ′ ″		
I	40 37 31.1	74 04 28.8	40 37 43.5	74 02 27.9	In Upper Bay.	
II	40 38 20.4	74 04 22.7	40 38 07.6	74 02 16.6	Do.	
III	40 39 16.5	74 03 56.5	40 38 31.1	74 01 47.6	Do.	
IV	40 40 19.5	74 03 30.3	40 39 07.6	74 01 16.0	Do.	
V	40 40 41.6	74 03 02.1	40 40 09.5	74 01 09.5	Do.	
VI	40 41 19.4	74 02 37.6	40 40 46.0	74 01 09.6	Do.	
VII	40 41 54.0	74 02 22.4	40 41 32.6	74 01 14.0	Do.	
VIII	40 42 10.2	74 00 19.3	40 41 59.2	73 59 57.3	In East River.	
IX	40 42 23.4	73 59 57.2	40 42 12.9	73 59 42.3	Do.	
X	40 42 32.9	73 58 50.2	40 42 19.0	73 58 49.3	Do.	
XI	40 42 37.8	73 58 41.6	40 42 17.8	73 58 26.8	Do.	
XII	40 42 39.9	73 58 37.6	40 42 30.8	73 58 14.8	Do.	
XIII	40 43 13.3	73 58 25.9	40 43 04.8	73 58 02.4	Do.	
XIV	40 43 20.0	73 58 21.7	40 43 11.4	73 57 54.8	Do.	
XV	40 43 33.9	73 58 20.8	40 43 35.4	73 57 43.6	Do.	
XVI	40 43 51.6	73 58 27.2	40 43 57.6	73 57 46.6	Do.	
XVII	40 44 25.5	73 58 29.0	40 44 06.0	73 57 38.5	Do.	
XVIII	40 44 42.5	73 58 14.8	40 44 29.2	73 57 40.9	Do.	
XIX	40 45 04.2	73 57 56.2	40 44 51.5	73 57 26.2	Do.	
XX	40 45 03.0	73 57 34.5	40 44 55.8	73 57 20.2	Easterly channel..	In Blackwell's Island channels.
XX	40 45 11.4	73 57 51.5	40 45 04.7	73 57 38.0	Westerly channel.	
XXI	40 45 17.5	73 57 18.8	40 45 11.9	73 57 07.5	Easterly channel..	
XXI	40 45 25.7	73 57 36.1	40 45 19.9	73 57 23.8	Westerly channel.	
XXII	40 45 32.0	73 57 04.9	40 45 27.5	73 56 54.9	Easterly channel..	
XXII	40 45 39.3	73 57 20.8	40 45 34.8	73 57 10.8	Westerly channel.	
XXIII	40 45 48.1	73 56 51.3	40 45 43.8	73 56 42.2	Easterly channel..	
XXIII	40 45 54.9	73 57 06.7	40 45 50.5	73 56 57.6	Westerly channel	
XXIV	40 46 02.0	73 56 38.0	40 45 58.8	73 56 30.3	Easterly channel..	
XXIV	40 46 08.7	73 56 54.9	40 46 02.6	73 56 46.3	Westerly channel.	
XXV	40 46 14.0	73 56 28.8	40 46 06.1	73 56 13.2	Easterly channel..	
XXV	40 46 20.9	73 56 42.0	40 46 16.5	73 56 33.3	Westerly channel.	
XXVI	40 42 20.4	74 02 02.4	40 42 17.4	74 01 10.8	In Hudson River.	
XXVII	40 42 35.2	74 02 05.6	40 42 28.0	74 01 05.8	Do.	
XXVIII	40 43 07.6	74 01 50.3	40 43 04.8	74 00 56.2	Do.	
XXIX	40 43 41.8	74 01 44.8	40 43 37.8	74 00 50.8	Do.	
XXX	40 44 13.0	74 01 32.6	40 44 06.8	74 00 45.4	Do.	
XXXI	40 44 38.9	74 01 24.4	40 44 33.4	74 00 43.4	Do.	
XXXII	40 44 54.2	74 01 29.6	40 44 50.0	74 00 40.2	Do.	
XXXIII	40 45 36.0	74 01 25.4	40 45 15.6	74 00 30.2	Do.	
XXXIV	40 46 07.6	74 01 01.6	40 45 45.8	74 00 10.8	Do.	
XXXV	40 46 38.9	74 00 32.8	40 46 15.7	73 59 42.8	Do.	
XXXVI	40 46 56.2	74 00 16.2	40 46 35.7	73 59 28.6	Do.	
XXXVII	40 47 27.3	73 59 57.8	40 47 07.4	73 59 08.4	Do.	

NOTE.—The positions given above are from determinations of latitude and longitude in 1875, corresponding to the position of New York City Hall, latitude 40° 42′ 43″.57, longitude 74° 00′ 23″.71; New York Trinity Church spire, latitude 40° 42′ 26″.13, longitude 74° 00′ 44″.85; Brooklyn City Hall, latitude 40° 41′ 31″.66, longitude 73° 59′ 27″.15.

Transverse curves of velocity, and perimeters.

SECTION I.

Distance from Staten Island shore.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.0	8.3	0.12	4.4	Latitude, 40° 37′ 31″.1; longitude, 74° 04′ 28″.8; bulkhead.
200	0.10	10.3	0.27	6.4	
400	0.18	10.3	0.45	6.4	
600	0.20	15.3	0.60	11.4	
800	0.31	15.3	0.73	11.4	
1,000	0.41	22.3	0.91	18.4	
1,200	0.72	26.3	1.09	22.4	
1,400	0.94	27.3	1.23	23.4	
1,600	1.15	34.3	1.50	30.4	
1,800	1.34	38.3	1.61	34.4	
2,000	1.44	44.3	1.61	40.4	
2,200	1.54	51.3	1.70	47.4	
2,400	1.57	51.3	1.78	47.4	
2,600	1.63	58.3	1.80	54.4	
2,800	1.65	57.3	1.84	53.4	
3,000	1.65	57.3	1.86	53.4	
3,200	1.65	57.3	1.90	53.4	
3,400	1.65	57.3	1.91	53.4	
3,600	1.63	57.3	1.92	53.4	
3,800	1.67	57.3	1.92	53.4	
4,000	1.68	52.3	1.92	48.4	Area of section: Flood, 360,228 square feet; ebb, 323,479 square feet.
4,200	1.70	52.3	1.92	48.4	
4,400	1.68	51.3	1.92	47.4	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 4,440 feet.
4,600	1.67	50.3	1.92	46.4	
4,800	1.67	50.3	1.90	46.4	
5,000	1.67	47.3	1.82	43.4	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 4,422 feet; ebb, 4,381 feet.
5,200	1.66	43.3	1.80	39.4	
5,400	1.66	42.3	1.80	38.4	
5,600	1.66	41.3	1.80	37.4	
5,800	1.66	38.3	1.77	34.4	
6,000	1.65	35.3	1.74	31.4	
6,200	1.54	34.3	1.68	30.4	
6,400	1.53	32.3	1.68	28.4	
6,600	1.53	31.3	1.64	27.4	
6,800	1.53	31.3	1.62	27.4	
7,000	1.53	32.3	1.59	28.4	
7,200	1.52	33.3	1.59	29.4	
7,400	1.52	33.3	1.61	29.4	
7,600	1.52	33.3	1.58	29.4	
7,800	1.52	37.3	1.58	33.4	
8,000	1.46	37.3	1.56	33.4	
8,200	1.25	37.3	1.53	33.4	
8,400	1.15	38.3	1.46	34.4	
8,600	0.93	36.3	1.42	32.4	
8,800	0.72	31.3	1.32	27.4	
9,000	0.43	32.3	1.20	28.4	
9,200	0.13	24.3	0.86	20.4	
9,400	0.00	14.3	0.00	10.4	Shore line of Long Island.
9,423	0.0	3.9	0.00	0.0	Latitude, 40° 37′ 43″.5; longitude, 74° 02′ 27″.9.

Transverse curves of velocity, and perimeters—Continued.

SECTION II.

Distance from origin.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.57	24.0	0.15	20.5	Latitude, 40° 38′ 20″.4; longitude, 74° 04′ 22″.7.
200	1.04	23.0	0.32	19.5	
400	1.28	35.0	0.55	31.5	
600	1.40	38.0	0.60	34.5	
800	1.42	40.0	0.72	36.5	
1,000	1.47	39.0	0.80	35.5	
1,200	1.52	41.0	1.00	37.5	
1,400	1.53	44.0	1.10	40.5	
1,600	1,53	45.0	1.20	41.5	
1,800	1.54	44.0	1.40	40.5	
2,000	1.54	48.0	1.47	44.5	
2,200	1.58	55.0	1.68	51.5	
2,400	1.59	59.0	1.80	55.5	
2,600	1.59	58.0	1.90	54.5	
2,800	1.61	61.0	2.00	57.5	
3,000	1.61	59.0	2.12	55.5	
3,200	1.61	61.0	2.27	57.5	
3,400	1.61	57.0	2.32	53.5	
3,600	1.59	57.0	2.30	53.5	
3,800	1.56	53.0	2.27	49.5	
4,000	1.54	53.0	2.20	49.5	
4,200	1.56	45.0	2.10	41.5	Area of section: Flood, 368,564 square feet; ebb, 334,149 square feet.
4,400	1.61	47.0	2.00	43.5	
4,600	1.63	47.0	1.93	43.5	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 3,790 feet.
4,800	1.63	34.0	1.90	30.5	
5,000	1.68	35.0	1.82	31.5	
5,200	1.70	35.0	1.73	31.5	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 3,689 feet; ebb, 3,814 feet.
5,400	1.66	30.0	1.62	26.5	
5,600	1.61	30.0	1.58	26.5	
5,800	1.56	27.0	1.50	23.5	
6,000	1.52	27.0	1.42	23.5	
6,200	1.42	26.0	1.32	22.5	
6,400	1.37	25.0	1.30	21.5	
6,600	1.33	28.0	1.28	24.5	
6,800	1.25	28.0	1.28	24.5	
7,000	1.23	24.0	1.28	20.5	
7,200	1.23	28.0	1.28	24.5	
7,400	1.21	30.0	1.29	26.5	
7,600	1.19	31.0	1.30	27.5	
7,800	1.16	28.0	1.30	24.5	
8,000	1.14	31.0	1.32	27.5	
8,200	1.14	31.0	1.38	27.5	
8,400	1.09	34.0	1.39	30.5	
8,600	1.02	39.0	1.32	35.5	
8,800	0.95	39.0	1.20	35.5	
9,000	0.84	30.0	0.90	26.5	
9,200	0.65	26.0	0.54	22.5	
9,400	0.38	17.0	0.00	13.5	
9,600	0.00	6.0	0.00	2.5	
9,833	0.00	4.0	0.00	0.5	Latitude, 40° 38′ 07″.6; longitude, 74° 02′ 16″.6.

Transverse curves of velocity, and perimeters—Continued.

SECTION III.

Distance from origin.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	1.26	16.2	0.49	11.0	Latitude, 40° 39′ 16″.5; longitude, 74° 03′ 56″.5.
200	1.43	16.2	0.69	11.0	
400	1.55	19.2	0.86	14.0	
600	1.63	28.2	1.02	23.0	
800	1.68	34.2	1.17	29.0	
1,000	1.70	51.2	1.29	46.0	
1,200	1.71	55.2	1.40	50.0	
1,400	1.70	60.2	1.50	55.0	
1,600	1.69	61.2	1.59	56.0	
1,800	1.67	61.2	1.67	56.0	
2,000	1.66	53.2	1.74	48.0	
2,200	1.63	51.2	1.79	46.0	
2,400	1.62	49.2	1.84	44.0	
2,600	1.60	45.2	1.87	40.0	
2,800	1.58	45.2	1.89	40.0	
3,000	1.57	42.2	1.90	37.0	
3,200	1.55	41.2	1.90	36.0	
3,400	1,54	38.2	1.90	33.0	
3,600	1.52	36.2	1.88	31.0	
3,800	1.50	36.2	1.87	31.0	
4,000	1.49	41.2	1.85	36.0	
4,200	1.47	35.2	1.81	30.0	
4,400	1.46	33.2	1.77	28.0	
4,600	1.44	31.2	1.74	26.0	
4,800	1.43	31.2	1.68	26.0	
5,000	1.40	28.2	1.64	23.0	Area of section: Flood, 348,894 square feet; ebb, 292,064 square feet.
5,200	1.38	31.2	1.56	26.0	
5,400	1.36	28.2	1.52	23.0	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 3,892 feet.
5,600	1.36	28.2	1.47	23.0	
5,800	1.35	25.2	1.36	20.0	
6,000	1,32	25.2	1.28	20.0	Mid-volume, or distance, from the origin of a vertical line which divides the volume passing through the section into two equal parts = flood, 3,214 feet; ebb, 3,246 feet.
6,200	1.32	24.2	1.16	19.0	
6,400	1.28	23.2	1.04	18.0	
6,600	1.26	22.2	0.96	17.0	
6,800	1.24	22.2	0.84	17.0	
7,000	1,20	22.2	0.76	17.0	
7,200	1.18	20.2	0.72	15.0	
7,400	1.12	20.2	0.64	15.0	
7,600	1.09	22.2	0.60	17.0	
7,800	1.06	25.2	0.56	20.0	
8,000	1.00	24.2	0.48	19.0	
8,200	0.96	27.2	0.48	22.0	
8,400	0.93	34.2	0.40	29.0	
8,600	0.84	40.2	0.36	35.0	
8.800	0.76	39.2	0.32	34.0	
9,000	0.76	38.2	0.32	33.0	
9,200	0.64	37.2	0.28	32.0	
9,400	0.56	29.2	0.24	24.0	
9,600	0.48	28.2	0.20	23.0	
9,800	0.40	22.2	0.16	17.0	
10,000	0.32	18.2	0.12	13.0	
10,200	0.20	11.2	0.08	6.0	
10,400	0.14	8.2	0.00	3.0	
10,600	0.04	7.2	0.00	2.0	
10,800	0.00	6.2	0.00	1.0	
10,929	0.00	5.2	0.00	0.0	Latitude, 40° 38′ 31″.1; longitude, 74° 01′ 47″.6.

Transverse curves of velocity, and perimeters—Continued.

SECTION IV.

Distance from origin.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.51	10.8	0.09	5.5	Latitude, 40° 40′ 19″.5; longitude, 74° 03′ 30″.3.
200	0.55	11.3	0.17	6.0	
400	0.60	11.3	0.25	6.0	
600	0.64	16.8	0.36	11.5	
800	0.70	17.8	0,49	12.5	
1,000	0.76	21.8	0.66	16.5	
1,200	0.84	24.8	0.91	19.5	
1,400	0.95	33.8	1.30	28.5	
1,600	1.07	42.8	1.57	37.5	
1,800	1.13	44.8	1.72	39.5	
2,000	1.15	48.8	1.79	43.5	
2,200	1.15	54.8	1.84	49.5	
2,400	1.14	56.8	1.87	51.5	
2,600	1.13	59.8	1.89	54.5	
2,800	1.11	57.8	1.89	52.5	
3,000	1.10	58.8	1.90	53.5	
3,200	1.09	58.8	1.90	53.5	
3,400	1.07	58.8	1.90	53.5	
3,600	1.96	57.8	1.90	52.5	
3,800	1.05	57.8	1.91	52.5	
4,000	1.03	52.8	1.92	47.5	
4,200	1.02	42.8	1.93	37.5	
4,400	1.01	38.8	1.92	33.5	
4,600	0.99	38.8	1.92	33.5	Area of section: Flood, 375,624 square feet; ebb, 308,542 square feet.
4,800	0.98	37.8	1.90	32.5	
5,000	0.96	32.8	1.86	27.5	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=4,240 feet.
5,200	0.95	31.8	1.78	26.5	
5,400	0.94	31.8	1.67	26.5	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 3,897 feet; ebb, 3,826 feet.
5,600	0.91	30.8	1.54	25.5	
5,800	0.90	28.8	1.41	23.5	
6,000	0.88	28.8	1.30	23.5	
6,200	0.86	25.8	1.23	20.5	
6,400	0.85	24.8	1.17	19.5	
6,600	0.83	24.8	1.12	19.5	
6,800	0.80	23.4	1.09	18.5	
7,000	0.79	24.3	1.06	19.0	
7,200	0.79	22.8	1.05	17.5	
7,400	0.77	22.8	1.04	17.5	
7,600	0.76	22.8	1.03	17.5	
7,800	0.76	21.8	1.02	16.5	
8,000	0.75	22.8	1.01	17.5	
8,200	0.74	20.8	1.01	15.5	
8,400	0.75	21.3	1.00	16.0	
8,600	0.72	18.8	1.00	13.5	
8,800	0.72	18.3	1.00	13.0	
9,000	0.70	18.3	0.99	13.0	
9,200	0.70	18.3	0.98	13.0	
9,400	0.70	18.8	0.97	13.5	
9,600	0.69	18.8	0.97	13.5	
9,800	0.69	18.8	0.96	13.5	
10,000	0.69	17.8	0.94	12.5	
10,200	0.66	22.8	0.91	17.5	

Transverse curves of velocity, and perimeters—Continued.

SECTION IV—Continued.

Distance from origin.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
10, 400	0. 64	23. 8	0. 89	18. 5	
10, 600	0. 62	27. 8	0. 86	22. 5	
10, 800	0. 60	26. 8	0. 82	21. 5	Area of section: Flood, 375,624 square feet; ebb, 308,542 square feet.
11, 000	0. 58	26. 8	0. 77	21. 5	
11, 200	0. 53	23. 3	0. 72	18. 0	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=4,240 feet.
11, 400	0. 48	20. 8	0. 60	15. 5	
11, 600	0. 43	19. 8	0. 60	14. 5	
11, 800	0. 37	19. 8	0. 53	14. 5	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 3,897 feet; ebb, 3,826 feet.
12, 000	0. 29	16. 8	0. 44	11. 5	
12, 200	0. 20	12. 8	0. 32	7. 5	
12, 400	0. 08	7. 8	0. 21	2. 5	
12, 600	—0. 05	7. 8	0. 05	2. 5	
12, 657	—0. 08	7. 8	0. 00	2. 5	Latitude, 40° 39′ 07″.6; longitude, 74° 01′ 16″.0.

Transverse curves of velocity, and perimeters—Continued.

SECTION V.

Distance from origin.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	1.03	14.5	1.73	10.5	Latitude, 40° 40′ 41″.6; longitude, 74° 03′ 02″.1.
200	1.00	14.5	1.86	10.5	
400	0.97	13.5	1.94	9.5	
600	0.96	19.5	1.99	15.5	
800	0.97	17.5	2.00	13.5	
1,000	1.01	30.5	1.98	26.5	
1,200	1.10	45.5	1.92	41.5	
1,400	1.20	51.5	1.87	47.5	
1,600	1.27	53.5	1.83	49.5	
1,800	1.33	56.5	1.82	52.5	
2,000	1.36	62.5	1.84	58.5	
2,200	1.38	61.5	1.88	57.5	
2,400	1.39	57.5	1.97	53.5	
2,600	1.39	57.5	2.03	53.5	
2,800	1.38	57.5	2.10	53.5	
3,000	1.37	58.5	2.15	54.5	
3,200	1.34	57.5	2.17	53.5	
3,400	1.32	50.5	2.19	46.5	
3,600	1.29	43.5	2.19	39.5	
3,800	1.24	42.5	2.17	38.5	
4,000	1.20	40.5	2.15	36.5	Area of section: Flood, 313,200 square feet; ebb, 276,200 square feet.
4,200	1.16	34.5	2.11	30.5	
4,400	1.11	34.5	2.05	30.5	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 3,450 feet.
4,600	1.07	35.5	1.99	31.5	
4,800	1.03	33.5	1.91	29.5	
5,000	0.99	36.5	1.81	32.5	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 3,219 feet; ebb, 3,252 feet.
5,200	0.96	31.5	1.73	27.5	
5,400	0.93	29.5	1.61	25.5	
5,600	0.91	31.5	1.51	27.5	
5,800	0.90	32.5	1.44	28.5	
6,000	0.89	32.5	1.38	28.5	
6,200	0.88	32.5	1.34	28.5	
6,400	0.87	30.5	1.30	26.5	
6,600	0.87	26.5	1.28	22.5	
6,800	0.88	26.5	1.27	22.5	
7,000	0.89	22.5	1.26	18.5	
7,200	0.90	21.5	1.26	17.5	
7,400	0.90	18.5	1.27	14.5	
7,600	0.91	17.5	1.28	13.5	
7,800	0.92	17.5	1.29	13.5	
8,000	0.93	16.5	1.31	12.5	
8,200	0.94	15.5	1.34	11.5	
8,400	0.95	15.5	1.38	11.5	
8,600	0.95	22.5	1.42	18.5	
8,800	0.96	23.5	1.46	19.5	
9,000	0.97	20.5	1.50	16.5	
9,200	0.98	10.5	1.53	6.5	
9,250	0.98	6.5	1.55	2.5	Latitude, 40° 40′ 09″.5; longitude, 74° 01′ 09″.5.

Transverse curves of velocity, and perimeters—Continued.

SECTION VI.

Distance from origin.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	—0. 11	9. 1	1. 48	4. 3	Latitude, 40° 41′ 19″.4; longitude, 74° 02′ 37″.6.
200	0. 06	16. 6	1. 56	11. 8	
400	0. 31	23. 1	1. 63	18. 3	
600	0. 63	23. 1	1. 70	18. 3	
800	0. 85	28. 1	1. 75	23. 3	
1, 000	1. 00	33. 1	1. 78	28. 3	
1, 200	1. 07	43. 1	1. 85	38. 3	
1, 400	1. 18	43. 1	1. 85	38. 3	
1, 600	1. 24	52. 1	1. 86	47. 3	
1, 800	1. 28	55. 1	1. 87	50. 3	
2, 000	1. 31	61. 1	1. 88	56. 3	
2, 200	1. 33	65. 1	1. 88	60. 3	
2, 400	1. 35	67. 1	1. 88	62. 3	
2, 600	1. 36	72. 1	1. 88	67. 3	
2, 800	1. 38	75. 1	1. 87	70. 3	
3, 000	1. 39	75. 1	1. 86	70. 3	
3, 200	1. 41	62. 1	1. 85	57. 3	Area of section: Flood, 311,814 square feet ebb, 275,603 square feet.
3, 400	1. 41	60. 1	1. 85	55. 3	
3, 600	1. 41	55. 1	1. 80	50. 3	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=3,180 feet.
3, 800	1. 41	43. 1	1. 77	38. 3	
4, 000	1. 40	40. 1	1. 75	35. 3	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 3,251 feet; ebb, 3,037 feet.
4, 200	1. 37	36. 1	1. 72	31. 3	
4, 400	1. 30	33. 1	1. 69	28. 3	
4, 600	1. 24	32. 1	1. 66	27. 3	
4, 800	1. 16	29. 1	1. 63	24. 3	
5, 000	1. 13	28. 1	1. 62	23. 3	
5, 200	1. 10	26. 1	1. 58	21. 3	
5, 400	1. 08	41. 1	1. 57	36. 3	
5, 600	1. 06	40. 1	1. 54	35. 3	
5, 800	1. 06	45. 1	1. 51	40. 0	
6, 000	1. 06	54. 1	1. 49	49. 0	
6, 200	1. 08	52. 1	1. 46	47. 3	
6, 400	1. 09	42. 1	1. 44	37. 3	
6, 600	1. 10	30. 1	1. 42	25. 3	
6, 800	1. 10	23. 1	1. 39	18. 3	
7, 000	1. 09	18. 1	1. 36	13. 3	
7, 200	1. 06	15. 1	1. 34	10. 3	
7, 400	1. 07	14. 1	1. 32	9. 3	
7, 544	0. 97	11. 1	1. 29	6. 3	Latitude, 40° 40′ 46″.0; longitude, 74° 01′ 09″.6.

Transverse curves of velocity, and perimeters—Continued.

SECTION VII.

Distance from Ellis Island.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0. 27	5. 8	0. 00	0. 0	Latitude, 40° 41′ 54″.0; longitude, 74° 02′ 22″.4.
200	0. 40	8. 3	0. 16	2. 5	
400	0. 50	13. 8	0. 39	8. 0	
600	0. 56	19. 8	0. 72	14. 0	
800	0. 63	19. 8	0. 98	14. 0	
1, 000	0. 64	22. 8	1. 15	17. 0	
1, 200	0. 66	27. 8	1. 23	22. 0	
1, 400	0. 68	28. 8	1. 30	23. 0	
1, 600	0. 72	31. 8	1. 45	26. 0	
1, 800	0. 77	34. 8	1. 53	29. 0	
2, 000	0. 83	37. 8	1. 63	32. 0	
2, 200	0. 92	45. 8	1. 74	40. 0	Area of section: Flood, 287,378 square feet; ebb, 254,504 square feet.
2, 400	1. 04	46. 8	1. 86	41. 0	
2, 600	1. 15	53. 8	1. 98	48. 0	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 3,500 feet.
2, 800	1. 24	72. 8	2. 09	67. 0	
3, 000	1. 31	89. 8	2. 15	84. 0	
3, 200	1. 36	88. 8	2. 18	83. 0	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 3,601 feet; ebb, 3,519 feet.
3, 400	1. 38	88. 8	2. 18	83. 0	
3, 600	1. 37	90. 8	2. 17	85. 0	
3, 800	1. 34	85. 8	2. 13	80. 0	
4, 000	1. 27	93. 8	2. 08	88. 0	
4, 200	1. 22	92. 8	2. 00	87. 0	
4, 400	1. 21	83. 8	1. 91	78. 0	
4, 600	1. 21	74. 8	1. 79	69. 0	
4, 800	1. 24	63. 8	1. 66	58. 0	
5, 000	1. 32	45. 8	1. 51	40. 0	
5, 200	1. 38	35. 8	1. 30	30. 0	
5, 400	1. 37	25. 8	1. 05	20. 0	
5, 600	1. 11	11. 8	0. 49	6. 0	
5, 668	0. 00	5. 8	0. 00	0. 0	Latitude, 40° 41′ 32″.6; longitude, 74° 01′ 14″.0.

Transverse curves of velocity, and perimeters—Continued.

SECTION VIII.

Distance from Brooklyn side.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.61	26.4	—0.31	22.7	Latitude, 40° 41′ 59″.2; longitude, 73° 59′ 57″.3.
100	0.98	51.6	0.08	47.9	
200	1.31	49.9	0.21	46.2	
300	1.53	47.1	0.57	43.4	
400	1.74	44.9	0.98	41.2	
500	1.92	44.4	1.43	40.7	
600	2.10	45.4	1.83	41.7	
700	2.22	46.7	2.16	43.0	Area of section: Flood. 93,750 square feet; ebb, 86,350 square feet.
800	2.32	47.4	2.36	43.7	
900	2.33	48.8	2.52	45.1	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 1,013 feet.
1,000	2.32	47.9	2.59	44.2	
1,100	2.25	49.7	2.62	46.0	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 965 feet; ebb, 1,182 feet.
1,200	2.13	52.4	2.62	48.7	
1,300	1.98	53.0	2.59	49.3	
1,400	1.81	52.4	2.54	48.7	
1,500	1.61	52.8	2.46	49.1	
1,600	1.40	51.5	2.32	47.8	
1,700	1.15	46.9	2.16	43.2	
1,800	0.90	41.4	1.93	37.7	
1,900	0.63	35.3	1.62	31.6	
2,000	0.05	29.8	1.26	26.1	Latitude, 40° 42′ 10″.2; longitude, 74° 00′ 19″.3.

SECTION IX.

0	1.85	50.0	0.26	46.3	Latitude, 40° 42′ 12.″9; longitude, 73° 59′ 42″.3.
100	1.89	51.0	1.32	47.3	
200	1.95	52.0	1.65	48.3	
300	2.09	52.3	1.86	48.6	
400	2.16	52.9	2.27	49.2	
500	2.16	57.5	2.41	53.8	Area of section: Flood, 82,766 square feet; ebb, 77,068 square feet.
600	2.13	64.0	2.51	60.3	
700	2.09	63.3	2.56	59.6	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=740 feet.
800	2.05	62.0	2.56	58.3	
900	2.00	61.2	2.49	57.5	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 700 feet; ebb, 753 feet.
1,000	1.95	60.5	2.35	56.8	
1,100	1.92	58.9	2.18	55.2	
1,200	1.84	54.7	1.97	51.0	
1,300	1.63	48.9	1.70	45.2	
1,400	1.33	34.7	1.42	31.0	
1,500	0.96	32.5	1.10	28.8	
1,540	0.74	30.3	0.90	26.6	Latitude, 40° 42′ 23″.4; longitude, 73° 59′ 57″.2.

Transverse curves of velocity, and perimeters—Continued.

SECTION X.

Distance from Brooklyn side.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.00	38.3	2.78	36.4	Latitude, 40° 42′ 19″.0; longitude, 73° 58′ 49″.3.
100	0.94	41.5	2.88	39.6	
200	1.37	47.9	2.94	45.9	
300	1.80	50.7	2.97	48.6	
400	2.37	54.1	2.98	52.1	Area of section: Flood, 59,362 square feet; ebb, 56,546 square feet.
500	2.98	54.3	2.98	52.3	
600	3.45	52.3	2.98	50.3	
700	3.61	51.0	2.94	49.0	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=600 feet.
800	3.66	45.7	2.87	43.2	
900	3.62	39.9	2.82	37.9	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 723 feet; ebb, 581 feet.
1,000	3.53	36.8	2.73	34.9	
1,100	3.35	32.8	2.65	30.9	
1,200	3.24	28.5	2.57	26.6	
1,300	2.94	26.1	2.44	24.0	
1,400	2.73	22.8	2.25	20.8	
1,408	2.59	20.3	2.24	18.3	Latitude, 40° 42′ 32″.9; longitude, 73° 58′ 50″.2.

SECTION XI.

0	0.00	19.1	0.00	16.6	Latitude, 40° 42′ 17″.8; longitude, 73° 58′ 26″.8.
100	0.07	20.6	0.00	18.1	
200	0.17	22.1	0.03	19.6	
300	0.32	24.1	0.06	21.6	
400	0.53	27.1	0.13	24.6	
500	0.82	32.1	0.20	28.6	
600	1.23	38.6	0.51	36.1	
700	1.69	44.6	0.80	42.1	
800	2.04	47.6	1.18	45.1	Area of section: Flood, 94,124 square feet; ebb, 88,299 square feet.
900	2.27	49.7	1.60	47.2	
1,000	2.51	53.6	2.06	51.1	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=1,237 feet.
1,100	2.67	55.6	2.38	53.1	
1,200	2.79	55.1	2.67	52.6	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 1,236 feet; ebb, 1,417 feet.
1,300	2.86	52.9	2.83	50.4	
1,400	2.85	49.1	2.89	46.6	
1,500	2.73	46.1	2.89	43.6	
1,600	2.46	44.1	2.86	41.6	
1,700	2.12	42.8	2.75	39.3	
1,800	1.65	42.3	2.57	39.8	
1,900	1.34	43.1	2.37	40.6	
2,000	0.79	43.6	2.11	41.1	
2,100	0.41	41.1	1.69	38.6	
2,200	0.04	37.1	1.16	34.6	
2,300	−0.23	26.6	0.41	24.1	
2,330	−0.32	23.1	0.17	20.6	Latitude, 40° 42′ 37″.8; longitude, 73° 58′ 41″.6.

Transverse curves of velocity, and perimeters—Continued.

SECTION XII.

Distance from Brooklyn side.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.00	25.2	0.00	23.1	Latitude, 40° 42′ 30″.8; longitude, 73° 58′ 14″.8.
100	1.45	30.7	0.23	28.6	
200	1.82	32.9	0.45	30.8	
300	1.95	33.2	0.68	31.1	
400	2.11	43.7	0.90	41.6	
500	2.22	45.3	1.17	43.2	
600	2.31	45.7	1.49	43.6	Area of section: Flood, 87,623 square feet; ebb, 83,444 square feet.
700	2.37	49.7	1.80	47.6	
800	2.42	50.0	2.20	47.9	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 1,039 feet.
900	2.48	49.7	2.61	47.6	
1,000	2.40	52.7	2.93	50.6	
1,100	2.39	51.7	3.11	49.6	
1,200	2.25	47.4	3.11	45.3	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 919 feet; ebb, 1,138 feet.
1,300	2.09	45.7	3.00	43.6	
1,400	1.87	45.7	2.81	43.6	
1,500	1.62	45.9	2.52	43.8	
1,600	1.37	44.1	2.25	42.0	
1,700	0.97	42.9	1.89	40.8	
1,800	0.65	45.2	1.44	43.1	
1,900	0.32	44.2	0.88	42.1	
1,990	0.00	43.2	0.00	41.1	Latitude, 40° 42′ 39″.9; longitude, 73° 58′ 37″.6.

SECTION XIII.

0	0.71	24.7	1.72	20.6	Latitude, 40° 43′ 04″.8; longitude, 73° 58′ 02″.4. Section begins at pier, Williamsburg.
100	1.54	31.2	2.01	27.1	
200	2.22	37.7	2.20	33.6	
300	2.37	46.2	2.35	42.1	
400	2.44	57.2	2.37	53.1	
500	2.48	69.2	2.37	65.1	
600	2.48	73.2	2.37	69.1	
700	2.46	70.2	2.37	66.1	Area of section: Flood, 83,697 square feet; ebb, 75,456 square feet.
800	2.37	58.2	2.37	54.1	
900	2.20	42.7	2.34	38.6	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 768 feet.
1,000	2.05	38.2	2.25	34.1	
1,100	1.88	35.7	2.08	31.6	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 689 feet; ebb, 718 feet.
1,200	1.68	34.7	1.80	30.6	
1,300	1.54	35.2	1.60	31.1	
1,400	1.40	31.7	1.59	27.6	
1,500	1.29	28.2	1.61	24.1	
1,600	1.17	27.7	1.62	23.6	
1,700	1.05	29.2	1.63	25.1	
1,800	0.97	29.2	1.65	25.1	
1,900	0.83	34.2	1.66	30.1	
2,000	0.68	24.7	1.61	20.6	[ends at pier 65, New York.
2,010	0.67	24.7	1.50	20.6	Latitude, 40° 43′ 13″.3; longitude, 73° 58′ 25″.9. Section

Transverse curves of velocity, and perimeters—Continued.

SECTION XIV.

Distance from Williamsburg side.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.00	21.5	1.23	19.3	Latitude, 40° 43′ 11″.4; longitude, 73° 57′ 54″.8. Section
100	0.74	30.5	1.58	28.3	begins at head of pier, Williamsburg.
200	1.47	34.0	1.75	31.8	
300	1.93	42.0	1.91	39.8	
400	2.14	51.0	2.05	48.8	
500	2.28	57.0	2.17	54.8	
600	2.31	58.0	2.26	55.8	
700	2.30	58.0	2.34	55.8	
800	2.29	58.0	2.38	55.8	Area of section: Flood, 81,745 square feet; ebb, 76,795
900	2.29	54.0	2.39	51.8	square feet.
1,000	2.25	50.0	2.40	47.8	Mid-area, or distance, from the origin, of a vertical line
1,100	2.21	48.0	2.41	45.8	which divides the section into two equal areas = 856 feet.
1,200	2.14	42.0	2.38	39.8	Mid-volume, or distance, from the origin, of a vertical
1,300	2.02	32.0	2.25	29.8	line which divides the volume passing through the section
1,400	1.91	23.0	2.17	20.8	into two equal parts = flood, 861 feet; ebb, 849 feet.
1,500	1.79	17.5	1.99	15.3	
1,600	1.66	18.0	1.84	15.8	
1,700	1.59	16.5	1.72	14.3	
1,800	1.55	19.5	1.69	17.3	
1 900	1.52	24.0	1.65	21.8	
2,000	1.49	25.0	1.62	22.8	
2,100	1.47	25.5	1.59	23.3	
2,200	1.43	25.0	1.59	22.8	Section ends at pier foot of Ninth street.
2,250	1.42	18.0	1.52	15.8	Latitude, 40° 43′ 20″.0; longitude, 73° 58′ 21″.7.

SECTION XV.

0	0.00	36.6	0.17	32.8	Latitude, 40° 43′ 35″.4; longitude, 73° 57′ 43″.6. Section
100	0.00	50.1	0.41	46.3	begins below Noble street, Williamsburg.
200	0.08	56.1	0.59	52.3	
300	0.62	53.1	0.70	49.3	
400	1.01	49.1	0.79	45.3	
500	1.33	58.1	0.86	54.3	
600	1.43	62.1	0.97	58.3	
700	1.50	60.1	1.07	56.3	
800	1.53	58.1	1.17	54.3	
900	1.57	62.1	1.25	58.3	
1,000	1.58	61.1	1.35	57.8	
1,100	1.58	61.1	1.43	57.3	Area of section: Flood, 137,052 square feet; ebb, 126,108
1,200	1.59	60.6	1.50	56.8	square feet.
1,300	1.58	60.1	1.52	56.3	Mid-area, or distance, from the origin, of a vertical line
1,400	1.57	59.1	1.55	55.3	which divides the section into two equal areas = 1,193 feet.
1,500	1.54	59.1	1.57	55.3	
1,600	1.50	58.1	1.59	54.3	Mid-volume, or distance, from the origin, of a vertical
1,700	1.42	57.6	1.60	53.8	line which divides the volume passing through the section
1,800	1.32	57.6	1.61	53.3	into two equal parts = flood, 1,222 feet; ebb, 1,399 feet.
1,900	1.20	57.6	1.61	53.3	
2,000	1.03	43.1	1.62	39.3	
2,100	0.91	32.1	1.62	28.3	
2,200	0.79	29.1	1.64	25.3	
2,300	0.70	27.6	1.55	23.8	
2,400	0.61	27.1	1.51	23.3	
2,500	0.53	27.1	1.45	23.3	
2,600	0.46	27.1	1.35	23.3	
2,700	0.39	21.1	1.25	17.3	
2,800	0.29	13.6	1.15	9.8	[ends foot of Fifteenth street, New York.
2,880	0.23	13.1	1.04	9.3	Latitude, 40° 43′ 33″.9; longitude, 73° 58′ 20″.8. Section

Transverse curves of velocity, and perimeters—Continued.

SECTION XVI.

Distance from Long Island side.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.85	17.2	0.50	14.2	Latitude, 40° 43′ 57″.6; longitude, 73° 57′ 46″.6. Section
100	1.74	19.2	0.84	16.2	begins at Bulkhead Dye House.
200	1.83	24.7	0.98	21.7	
300	1.90	35.7	1.09	32.7	
400	1.96	39.2	1.19	36.2	
500	2.01	39.7	1.26	36.7	
600	2.04	44.7	1.32	41.7	
700	2.07	46.2	1.36	43.2	
800	2.07	43.2	1.39	40.2	
900	2.07	41.2	1.40	38.2	
1,000	2.02	40.7	1.42	37.7	
1,100	1.94	44.7	1.43	41.7	
1,200	1.83	48.2	1.44	45.2	
1,300	1.70	50.7	1.48	47.7	Area of section: Flood, 113,340 square feet; ebb, 103,740
1,400	1.60	51.2	1.50	48.2	square feet.
1,500	1.48	51.2	1.58	48.2	Mid-area, or distance, from the origin, of a vertical line
1,600	1.46	44.7	1.66	41.7	which divides the section into two equal areas =1,411 feet.
1,700	1.27	42.2	1.75	39.2	Mid-volume, or distance, from the origin, of a vertical
1,800	1.16	39.7	1.81	36.7	line which divides the volume passing through the section
1,900	1.05	35.7	1.84	32.7	into two equal parts =flood, 1,135 feet; ebb, 1,502 feet.
2,000	0.96	33.2	1.86	30.2	
2,100	0.96	32.7	1.85	29.7	
2,200	0.96	32.2	1.81	29.2	
2,300	0.96	32.2	1.73	29.2	
2,400	0.94	32.7	1.59	29.7	
2,500	0.91	33.2	1.45	30.2	
2,600	0.89	30.7	1.31	27.7	
2 700	0.42	25.7	1.19	22.7	
2,800	0.00	24.7	1.05	21.7	
2,900	0.00	24.7	0.86	21.7	
3,000	0.00	19.7	0.63	16.7	
3,100	0.00	13.7	0.37	10.7	[ends at pier foot of Nineteenth street, New York.
3,200	0.00	13.2	0.00	10.2	Latitude, 40° 43′ 51″.6; longitude, 73° 58′ 27″.2. Section

Transverse curves of velocity, and perimeters—Continued.

SECTION XVII.

Distance from Long Island side.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.00	2.8	0.00	0.0	Latitude, 40° 44′ 06″.0; longitude, 73° 57′ 38″.5. Section begins at south side Newton Creek.
100	0.00	4.8	0.00	2.0	
200	0.00	7.8	0.00	5.0	
300	0.00	14.8	0.00	12.0	
400	0.00	18.8	0.03	16.0	
500	0.02	19.8	0.12	17.0	
600	0.04	24.8	0.25	22.0	
700	0.08	25.8	0.46	23.0	
800	0.23	27.8	0.71	25.0	
900	0.90	32.8	0.91	30.0	
1,000	1.19	34.3	1.02	31.5	
1,100	1.31	35.3	1.06	32.5	
1,200	1.40	36.8	1.10	34.0	
1,300	1.50	37.8	1.12	35.0	
1,400	1.52	38.8	1.13	36.0	
1,500	1.52	40.2	1.13	37.5	
1,600	1.50	42.3	1.13	39.5	
1,700	1.49	42.8	1.12	40.0	
1,800	1.51	42.8	1.12	40.0	Area of section: Flood, 163,106 square feet; ebb, 150,870 square feet.
1,900	1.44	43.8	1.12	41.0	
2,000	1.40	43.8	1.11	41.0	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=2,504 feet.
2,100	1.37	44.8	1.10	42.0	
2,200	1.34	45.8	1.08	43.0	
2,300	1.30	45.8	1.07	43.0	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 2,259 feet; ebb, 2,656 feet.
2,400	1.26	45.8	1.06	43.0	
2,500	1.19	45.8	1.07	43.0	
2,600	1.17	45.8	1.10	43.0	
2,700	1.14	47.8	1.13	45.0	
2,800	1.12	50.3	1.21	47.5	
2,900	1.08	49.8	1.26	47.0	
3,000	1.05	48.8	1.34	46.0	
3,100	1.01	48.3	1.37	45.5	
3,200	0.97	48.3	1.48	45.5	
3,300	0.92	49.8	1.55	47.0	
3,400	0.87	52.8	1.58	50.0	
3,500	0.81	54.3	1.60	51.5	
3,600	0.72	50.3	1.60	47.5	
3,700	0.62	43.3	1.52	40.5	
3,800	0.54	38.3	1.10	35.5	
3,900	0.44	37.8	0.24	35.0	
4,000	0.34	31.3	0.00	28.5	
4,100	0.23	25.3	0.00	22.5	
4,200	0.12	28.8	0.00	26.5	
4,300	0.00	28.8	0.00	26.0	[ends at Bulkhead above Twenty-ninth street.
4,370	0.00	28.8	0.00	26.0	Latitude, 40° 44′ 25″.5; longitude, 73° 58′ 29″.0. Section

Transverse curves of velocity, and perimeters—Continued.

SECTION XVIII.

Distance from Brooklyn side.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.00	28.1	0.23	25.5	Latitude, 40° 44′ 29″.2; longitude, 73° 57′ 40″.9. Section
100	1.06	28.1	0.61	25.5	begins at pier below Thirty-fourth street.
200	1.14	27.1	0.80	24.5	
300	1.25	31.1	0.94	28.5	
400	1.32	40.6	1.08	38.0	
500	1.37	46.6	1.15	44.0	
600	1.43	44.6	1.20	42.0	
700	1.46	43.1	1.21	40.5	
800	1.50	39.1	1.26	36.5	
900	1.55	35.6	1.28	33.0	
1,000	1.57	35.1	1.32	32.5	
1,100	1.60	36.1	1.32	33.5	
1,200	1.64	36.1	1.32	33.5	Area of section: Flood, 117,642 square feet; ebb, 109,998
1,300	1.67	36.1	1.35	33.5	square feet.
1,400	1.66	36.1	1.42	33.5	Mid-area, or distance, from the origin, of a vertical line
1,500	1.64	36.6	1.59	34.0	which divides the section into two equal areas = 1,620 feet.
1,600	1.60	37.1	1.86	34.5	Mid-volume, or distance, from the origin, of a vertical
1,700	1.58	37.1	2.09	34.5	line which divides the volume passing through the section
1,800	1.53	32.6	2.30	30.0	into two equal parts = flood, 1,508 feet; ebb, 1,693 feet.
1,900	1.48	12.6	2.39	10.0	
2,000	1.43	18.6	2.42	16.0	
2,100	1.38	42.1	2.39	39.5	
2,200	1.34	54.1	2.36	51.5	
2,300	1.32	55.6	2.22	53.0	
2,400	1.28	57.1	1.95	54.5	
2,500	1.26	56.1	1.65	53.5	
2,600	1.23	55.1	1.36	52.5	
2,700	1.14	53.1	1.06	50.5	
2,800	0.93	53.1	0.65	50.5	
2,900	0.62	51.6	0.18	49.0	[ends at pier foot of Thirty-eighth street, New York.
2,940	0.46	50.1	0.00	47.5	Latitude, 40° 44′ 42″.5; longitude, 73° 58′ 14″.8. Section

Transverse curves of velocity, and perimeters—Continued.

SECTION XIX

Distance from Brooklyn side.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.48	7.0	0.64	4.6	Latitude, 40° 44′ 51″.5; longitude, 73° 57′ 26″.2. Section begins at shore line, Hunter's Point.
100	1.24	22.0	0.95	19.6	
200	1.39	29.0	1.22	26.6	
300	1.41	31.0	1.37	28.6	
400	1.41	33.0	1.52	30.6	
500	1.41	35.0	1.65	32.6	
600	1.41	36.0	1.68	33.6	
700	1.40	38.0	1.68	35.6	
800	1.39	38.5	1.67	36.1	
900	1.38	39.5	1.58	37.1	
1,000	1.38	41.5	1.33	39.1	Area of section: Flood, 98,920 square feet; ebb, 92,608 square feet.
1,100	1.38	42.5	1.04	40.1	
1,200	1.37	31.0	0.80	28.6	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 1,660 feet.
1,300	1.38	25.0	0.84	22.6	
1,400	1.40	16.0	1.04	13.6	
1,500	1.43	11.0	1.30	8.6	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 1,862 feet; ebb, 1,865 feet.
1,600	1.43	26.5	1.76	24.1	
1,700	1.45	38.0	2.03	35.6	
1,800	1.46	38.0	2.26	35.6	
1,900	1.50	41.0	2.41	39.6	
2,000	1.61	49.0	2.45	46.6	
2,100	1.85	56.0	2.44	53.6	
2,200	2.02	60.0	2.35	57.6	
2,300	2.12	65.0	2.12	62.6	
2,400	2.14	65.0	1.80	62.6	
2,500	2.10	54.0	1.43	51.6	
2,600	2.00	30.0	1.10	27.6	
2,630	1.90	28.0	0.99	25.6	Latitude, 40° 45′ 04″.2; longitude, 73° 57′ 56″.2. Section ends at Bulkhead, foot Forty-eighth street.

Transverse curves of velocity, and perimeters—Continued.

SECTION XX.

EASTERLY CHANNEL, BLACKWELL'S ISLAND.

Distance from Blackwell's Island.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0. 97	6. 24	0. 22	6. 2	Latitude, 40° 45′ 03″.0; longitude, 73° 57′ 34″.5.
100	2. 09	17. 2	1. 04	17. 3	
200	2. 19	34. 7	1. 26	34. 8	
300	2. 22	39. 8	1. 57	39. 9	
400	2. 22	36. 7	1. 75	36. 8	Area of section: Flood, 33,225 square feet; ebb, 33,358 square feet.
500	2. 19	32. 7	1. 95	32. 8	
600	2. 07	32. 7	2. 07	32. 8	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 556 feet.
700	1. 95	29. 8	2. 17	29. 9	
800	1. 81	28. 7	2. 26	28. 8	
900	1. 61	25. 8	2. 34	25. 9	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 501 feet; ebb, 629 feet.
1, 000	1. 42	19. 8	2. 26	19. 9	
1, 100	1. 29	19. 7	2. 01	19. 8	
1, 200	1. 13	9. 8	1. 57	9. 9	
1, 300	0. 30	2. 2	0. 68	2. 3	
1, 334	0. 10	2. 2	0. 34	2. 3	Latitude, 40° 44′ 55″.8; longitude, 73° 57′ 20″.2.

SECTION XX.

WESTERLY CHANNEL, BLACKWELL'S ISLAND.

Distance from New York shore.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	1. 20	7. 0	0. 19	5. 9	Latitude, 40° 45′ 11″.4; longitude, 73° 57′ 51″..5
100	1. 84	22. 0	0. 68	20. 9	
200	2. 08	39. 0	1. 00	37. 9	
300	2. 00	49. 0	1. 70	47. 9	Area of section: Flood, 49,241 square feet; ebb, 47,882 square feet.
400	1. 92	61. 9	2. 53	60. 8	
500	1. 84	49. 0	3. 18	47. 9	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 629 feet.
600	1. 90	40. 0	3. 40	38. 9	
700	2. 10	43. 9	3. 33	42. 8	
800	2. 44	46. 0	3. 07	44. 9	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 715 feet; ebb, 649 feet.
900	2. 72	42. 8	2. 74	41. 7	
1, 000	3. 04	42. 8	2. 33	41. 7	
1, 100	3. 30	35. 4	1. 86	33. 9	
1, 200	3. 10	21. 0	1. 21	19. 9	
1, 236	2. 64	13. 0	0. 84	11. 9	Latitude, 40° 45′ 04″.7; longitude, 73° 57′ 38″.0.

Transverse curves of velocity, and perimeters—Continued.

SECTION XXI.

EASTERLY CHANNEL, BLACKWELL'S ISLAND.

Distance from Blackwell's Island.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	1.02	8.3	0.57	8.2	Latitude, 40° 45′ 17″.5; longitude 73° 57′ 18″.8.
100	1.84	31.4	2.37	31.3	
200	2.55	31.6	2.86	31.5	Area of section: Flood, 22,667 square feet; ebb, 22,565 square feet.
300	3.05	34.3	3.15	34.2	
400	3.54	27.4	3.40	27.3	
500	3.70	22.4	3.36	22.3	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=390 feet.
600	3.54	20.4	3.15	20.3	
700	3.23	20.3	2.86	20.2	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 435 feet; ebb, 401 feet.
800	2.72	16.4	2.55	16.3	
900	2.21	15.3	2.10	15.2	
1,000	1.44	4.3	0.97	4.2	
1,026	1.02	2.6	0.52	2.5	Latitude, 40° 45′ 11″.9; longitude, 73° 57′ 07″.5.

SECTION XXI.

WESTERLY CHANNEL, BLACKWELL'S ISLAND.

Distance from New York shore.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	1.51	5.1	0.76	4.3	Latitude, 40° 45′ 25″.7; longitude, 73° 57′ 36″.1.
100	2.25	21.1	2.07	20.3	
200	2.71	29.1	3.03	28.3	
300	2.97	46.0	4.00	45.2	Area of section: Flood, 39,600 square feet; ebb, 38,708 square feet.
400	3.15	60.0	3.71	58.3	
500	3.15	56.9	3.62	56.1	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=520 feet.
600	3.11	56.9	3.32	56.1	
700	2.92	38.1	2.94	37.3	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 509 feet; ebb, 490 feet.
800	2.69	38.1	2.51	37.3	
900	2.34	23.0	1.95	22.2	
1,000	1.89	23.0	1.43	21.3	
1,100	1.44	5.1	0.87	4.3	
1,115	1.08	2.9	0.65	2.1	Latitude, 40° 45′ 19″.9; longitude, 73° 57′ 23″.8.

Transverse curves of velocity, and perimeters—Continued.

SECTION XXII.

EASTERLY CHANNEL, BLACKWELL'S ISLAND.

Distance from Blackwell's Island.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	1.40	6.4	1.36	5.5	Latitude, 40° 45′ 32″.0; longitude, 73° 57′ 04″.9.
100	2.62	20.4	2.32	19.5	Area of section: Flood, 21,665 square feet; ebb, 20,854 square feet.
200	3.08	43.4	3.10	42.5	
300	3.29	38.4	3.49	37.5	
400	3.36	33.4	3.88	32.5	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=360 feet.
500	3.29	28.4	4.03	27.5	
600	3.01	17.4	3.49	16.5	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 361 feet; ebb, 375 feet.
700	2.69	15.4	2.71	14.5	
800	2.17	12.4	1.36	11.5	
900	1.26	8.4	0.19	7.5	
902	1.26	7.8	0.00	6.9	Latitude, 40° 45′ 27″.5; longitude, 73° 56′ 54″.9.

SECTION XXII.

WESTERLY CHANNEL, BLACKWELL'S ISLAND.

Distance from New York shore.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	2.05	22.4	0.84	22.0	Latitude, 40° 45′ 39″.3; longitude, 73° 57′ 20″.8.
100	2.75	45.5	2.10	45.1	Area of section: Flood, 40,794 square feet; ebb, 40,432 square feet.
200	2.96	65.4	3.06	65.0	
300	2.84	70.5	3.69	70.1	
400	2.84	57.5	3.78	57.1	Mid-area, or distance from the origin, of a vertical line which divides the section into two equal areas=370 feet.
500	2.97	52.5	3.43	57.1	
600	2.90	33.4	2.59	33.0	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 364 feet; ebb, 363 feet.
700	2.80	30.4	1.76	30.0	
800	2.28	28.4	1.18	28.0	
900	1.36	15.5	0.53	15.1	
905	1.29	2.4	0.59	2.0	Latitude, 40° 45′ 34″.8; longitude, 73° 57′ 10″.8.

Transverse curves of velocity, and perimeters—Continued.

SECTION XXIII.

EASTERLY CHANNEL, BLACKWELL'S ISLAND.

Distance from Blackwell's Island.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	2.20	7.3	1.32	6.9	Latitude, 40° 45′ 48″.1; longitude, 73° 56′ 51″.3.
100	3.30	12.3	2.42	11.9	Area of section: Flood, 17,856 square feet; ebb, 17,520 square feet.
200	3.74	22.2	3.19	21.8	
300	3.85	33.3	3.57	32.9	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=400 feet.
400	3.85	31.2	3.74	30.8	
500	3.25	19.3	3.33	18.9	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 391 feet; ebb, 382 feet.
600	3.61	22.3	2.64	23.9	
700	3.22	25.2	1.78	24.8	
800	2.42	8.3	0.88	7.9	
842	1.65	6.3	0.33	5.9	Latitude, 40° 45′ 43″.8; longitude, 73° 56′ 42″.2.

SECTION XXIII.

WESTERLY CHANNEL, BLACKWELL'S ISLAND.

Distance from New York shore.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	2.64	8.8	1.96	8.7	Latitude, 40° 45′ 54″.9; longitude, 73° 57′ 06″.7.
100	3.32	54.8	3.01	54.7	Area of section: Flood, 31,846 square feet; ebb, 31,765 square feet.
200	3.58	52.8	3.50	52.7	
300	3.68	52.2	3.72	52.1	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=340 feet.
400	3.76	49.8	3.72	49.7	
500	3.57	43.8	3.64	43.7	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 338 feet; ebb, 351 feet.
600	3.24	35.8	3.46	35.7	
700	2.80	16.8	3.22	16.7	
800	2.08	13.8	2.52	13.7	
812	1.84	7.2	2.45	7.1	Latitude, 40° 45′ 50″.5; longitude, 73° 56′ 57″.6.

Transverse curves of velocity, and perimeters—Continued.

SECTION XXIV.

EASTERLY CHANNEL, BLACKWELL'S ISLAND.

Distance from Blackwell's Island.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.64	17.1	0.71	16.2	Latitude, 40° 46′ 02″.0; longitude, 73° 56′ 38″.0.
100	2.05	35.4	2.00	34.5	Area of section: Flood, 18,063 square feet; ebb, 17,450 square feet.
200	3.81	35.3	4.15	34.4	
300	5.12	35.3	4.78	34.4	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=280 feet.
400	4.61	34.3	4.50	33.4	
500	3.11	22.3	3.76	21.4	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 313 feet; ebb, 303 feet.
600	2.24	8.1	2.33	7.2	
681	0.96	5.4	0.97	4.5	Latitude, 40° 45′ 58″.8; longitude, 73° 56′ 30″.3.

SECTION XXIV.

WESTERLY CHANNEL, BLACKWELL'S ISLAND.

Distance from New York shore.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	2.37	23.2	1.20	23.1	Latitude, 40° 46′ 08″.7; longitude, 73° 56′ 54″.9.
100	3.09	38.2	2.76	38.1	
200	3.59	44.2	3.50	44.1	Area of section: Flood, 38,401 square feet; ebb, 38,310 square feet.
300	3.91	62.2	4.00	62.1	
400	3.91	57.7	4.30	57.6	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=410 feet.
500	3.52	56.2	3.78	56.1	
600	2.50	38.2	2.30	38.1	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 367 feet; ebb, 366 feet.
700	1.33	38.2	0.90	38.1	
800	0.43	33.2	0.40	33.1	
900	0.05	7.2	0.18	7.1	
912	0.00	6.4	0.10	6.3	Latitude, 40° 46′ 02″.6; longitude, 73° 56′ 46″.3.

Transverse curves of velocity, and perimeters—Continued.

SECTION XXV.

WESTERLY CHANNEL, BLACKWELL'S ISLAND.

Distance from New York shore.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	1.51	7.8	2.01	7.9	Latitude, 40° 46′ 20″.9; longitude, 73° 56′ 42″.0.
100	3.81	16.8	3.12	16.9	Area of section: Flood, 31,256 square feet; ebb, 31,336 square feet.
200	4.03	52.8	3.48	52.9	
300	4.45	61.8	3.74	61.9	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=380 feet.
400	4.26	58.8	3.95	58.9	
500	3.92	42.8	4.06	42.9	
600	3.39	44.8	3.99	44.9	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 363 feet; ebb, 392 feet.
700	2.38	26.8	3.43	26.9	
800	1.17	7.8	2.62	7.9	
804	0.95	4.8	2.49	4.9	Latitude, 40° 46′ 16″.5; longitude, 73° 56′ 33″.3.

Transverse curves of velocity, and perimeters—Continued.

SECTION XXVI.

Distance from New York side.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	1.27	45.0	2.15	41.3	Latitude, 40° 42′ 17″.4; longitude, 74° 01′ 10″.8. Begin-
100	1.28	49.0	2.23	45.3	ning of section at end of pier 1, New York.
200	1.29	53.0	2.25	49.3	
300	1.30	55.2	2.25	51.5	
400	1.30	57.5	2.25	53.8	
500	1.30	57.8	2.25	54.1	
600	1.29	58.2	2.25	54.5	
700	1.29	56.6	2.25	52.9	
800	1.29	55.0	2.25	51.3	
900	1.28	53.0	2.24	49.3	
1,000	1.28	51.0	2.24	47.3	
1,100	1.28	49.5	2.23	45.8	
1,200	1.27	48.0	2.23	44.3	
1,300	1.27	47.0	2.23	43.3	
1,400	1.26	46.2	2.22	42.5	
1,500	1.26	45.8	2.22	42.1	
1,600	1.25	45.5	2.21	41.8	Area of section: Flood, 165,900 square feet; ebb, 151,100
1,700	1.24	44.4	2.21	40.7	square feet.
1,800	1.24	43.4	2.20	39.7	Mid-area, or distance, from the origin, of a vertical line
1,900	1.22	42.5	2.20	38.8	which divides the section into two equal areas = 1,570 feet.
2,000	1.21	41.7	2.19	38.0	
2,100	1,20	40.7	2.18	37.0	Mid-volume, or distance, from the origin, of a vertical
2,200	1.19	39.7	2.17	36.0	line which divides the volume passing through the section
2,300	1.17	39.3	2.17	35.6	into two equal parts = flood, 1,434 feet from pier 1, New
2,400	1.14	39.0	2.16	35.3	York side; ebb, 1,518 feet from pier 1, New York side.
2,500	1.12	37.9	2.14	34.2	
2,600	1.10	36.8	2.13	33.1	
2,700	1.07	35.6	2.12	31.9	
2,800	1.04	34.5	2.12	30.8	
2,900	1.02	34.1	2.09	30.4	
3,000	0.99	33.8	2.08	30.1	
3,100	0.96	32.6	2.07	28.9	
3,200	0.93	31.4	2.06	27.7	
3,300	0.90	30.4	2.05	26.7	
3,400	0.86	29.5	2.03	25.8	
3,500	0.82	29.0	2.02	25.3	
3,600	0.78	28.6	2.01	24.9	
3,700	0.74	25.8	2.00	22.1	
3,800	0.70	23.0	1.98	19.3	
3,900	0.65	23.0	1.97	19.3	[section at Communipaw Ferry slip.
4,000	0.61	23.0	1.95	19.3	Latitude, 40° 42′ 20″.4; longitude, 74° 02′ 02″.4. End of

Transverse curves of velocity, and perimeters—Continued.

SECTION XXVII.

Distance from Jersey shore.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.00	9.1	0.00	5.1	Latitude, 40° 42′ 35″.2; longitude, 74° 02′ 05″.6. Beginning of section at mouth of canal at Communipaw.
100	0.00	8.6	0.00	4.6	
200	0.05	8.3	0.00	4.3	
300	0.21	8.6	0.20	4.6	
400	0.34	10.1	0.55	6.1	
500	0.47	15.1	0.90	11.1	
600	0.60	20.6	1.30	16.6	
700	0.70	23.6	1.73	19.6	
800	0.80	24.8	2.07	20.8	
900	0.89	25.6	2.35	21.6	
1,000	0.94	29.6	2.48	25.6	
1,100	1.05	29.6	2.48	25.6	
1,200	1.10	31.1	2.47	27.1	
1,300	1.14	32.6	2.47	28.6	
1,400	1.17	33.6	2.45	29.6	
1,500	1.21	33.6	2.45	29.6	
1,600	1.25	34.1	2.45	30.1	
1,700	1.27	35.3	2.47	31.3	
1,800	1.28	36.1	2.47	32.1	
1,900	1.28	36.6	2.47	32.6	
2,000	1.29	36.1	2.47	32.1	Area of section: Flood, 180,990 square feet; ebb, 162,190 square feet.
2,100	1.30	35.6	2.48	31.6	
2,200	1.30	36.1	2.49	32.1	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=3,090 feet.
2,300	1.30	36.6	2.49	32.6	
2,400	1.30	37.1	2.48	33.1	
2,500	1.30	39.1	2.47	35.1	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 2,980 feet; ebb, 2,700 feet.
2,600	1.30	40.6	2.47	36.6	
2,700	1.30	41.6	2.45	37.6	
2,800	1.30	42.1	2.37	38.1	
2,900	1.29	43.1	2.36	39.1	
3,000	1.29	45.1	2.35	41.1	
3,100	1.29	46.6	2.30	42.6	
3,200	1.29	45.1	2.26	41.1	
3,300	1.28	48.1	2.17	44.1	
3,400	1.28	48.6	2.13	44.6	
3,500	1.27	52.1	2.08	48.1	
3,600	1.26	52.1	2.03	48.1	
3,700	1.25	54.1	1.99	50.1	
3,800	1.23	55.1	1.95	51.1	
3,900	1.22	56.1	1.91	52.1	
4,000	1.21	59.6	1.85	55.6	
4,100	1.18	63.1	1.77	59.1	
4,200	1.12	67.6	1.67	63.6	
4,300	1.01	63.1	1.53	59.1	
4,400	0.80	60.6	1.39	56.6	
4,500	0.44	56.6	1.13	52.6	
4,600	0.00	46.8	1.00	42.8	[section at head of pier No. 6, New York.
4,700	0.00	39.1	0.48	35.1	Latitude, 40° 42′ 28″.0; longitude, 74° 01′ 05″.8. End of

Transverse curves of velocity, and perimeters—Continued.

SECTION XXVIII.

Distance from Jersey side.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.42	20.1	0.00	16.1	Latitude, 40° 43′ 07″.6; longitude, 74° 01′ 50″.3. Beginning of section at Dodge, Meigs & Dodge wharf.
100	0.57	24.6	0.53	20.6	
200	0.68	28.1	1.22	24.1	
300	0.77	30.6	1.51	26.6	
400	0.83	31.1	1.94	27.1	
500	0.90	32.1	2.06	28.1	
600	0.96	33.8	2.09	29.8	
700	1.02	34.1	2.10	30.1	
800	1.07	35.6	2.10	31.6	
900	1.09	35.1	2.15	31.1	
1,000	1.13	35.1	2.16	31.1	
1,100	1.15	36.6	2.19	32.6	
1,200	1.18	37.1	2.21	33.1	
1,300	1.20	38.1	2.25	34.1	
1,400	1.21	37.6	2.28	33.6	
1,500	1.22	38.1	2.29	34.1	
1,600	1.24	38.1	2.31	34.1	
1,700	1.25	37.6	2.32	33.6	Area of section: Flood, 176,960 square feet; ebb, 160,160 square feet.
1,800	1.25	38.6	2.35	34.6	
1,900	1.27	37.6	2.36	33.6	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 2,510 feet.
2,000	1.29	38.6	2.36	34.6	
2,100	1.29	39.3	2.36	35.3	
2,200	1.31	40.6	2.33	36.6	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 2,521 feet; ebb, 2,457 feet.
2,300	1.31	43.1	2.32	39.1	
2,400	1.32	42.6	2.29	38.6	
2,500	1.33	44.6	2.26	40.6	
2,600	1.34	44.6	2.22	40.6	
2,700	1.34	47.1	2.19	43.1	
2,800	1.36	48.6	2.17	44.6	
2,900	1.37	52.1	2.15	48.1	
3,000	1.38	53.1	2.14	49.1	
3,100	1.37	55.1	2.12	51.1	
3,200	1.32	59.1	2.11	55.1	
3,300	1.28	60.1	2.10	56.1	
3,400	1.24	60.1	2.09	56.1	
3,500	1.17	60.1	2.04	56.1	
3,600	1.09	59.6	1.96	55.6	
3,700	1.01	57.1	1.85	53.1	
3,800	0.92	53.1	1.71	49.1	
3,900	0.79	49.6	1.54	45.6	
4,000	0.65	41.6	1.41	37.6	
4,100	0.54	37.1	1.22	33.1	[section at head of pier 33, New York.
4,200	0.36	26.1	0.99	22.1	Latitude, 40° 43′ 04″.8; longitude, 74° 00′ 56″.2. End of

Transverse curves of velocity, and perimeters—Continued.

SECTION XXIX.

Distance from Jersey side.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.22	23.6	0.71	19.6	Latitude, 40° 43′ 41″.8; longitude, 74° 01′ 44″.8. Beginning
100	0.39	21.3	1.06	17.3	of section at head of pier 9, Jersey City.
200	0.44	24.1	1.23	20.1	
300	0.54	28.6	1.39	24.6	
400	0.63	31.1	1.56	27.1	
500	0.71	32.4	1.71	28.4	
600	0.75	34.1	1.86	30.1	
700	0.83	35.1	1.96	31.1	
800	0.89	36.6	2.05	32.6	
900	0.92	36.8	2.14	32.8	
1,000	1.00	37.4	2.21	33.4	
1,100	1.03	38.4	2.25	34.4	
1,200	1.07	39.4	2.30	35.4	
1,300	1.08	39.4	2.34	35.4	
1,400	1.12	39.4	2.40	35.4	
1,500	1.13	39.6	2.44	35.6	
1,600	1.15	39.8	2.47	35.8	
1,700	1.17	40.8	2.48	36.8	Area of section: Flood, 182,220 square feet; ebb, 165,420
1,800	1.21	41.1	2.48	37.1	square feet.
1,900	1.25	43.4	2.48	39.4	Mid-area, or distance, from the origin, of a vertical line
2,000	1.28	43.8	2.48	39.8	which divides the section into two equal areas = 2,480
2,100	1.29	43.8	2.48	39.8	feet.
2,200	1.31	43.8	2.48	39.8	Mid-volume, or distance, from the origin, of a vertical
2,300	1.33	43.8	2.48	39.8	line which divides the volume passing through the sec-
2,400	1.35	44.4	2.47	40.4	tion into two equal parts = flood, 2,660 feet; ebb, 2,319
2,500	1.36	45.1	2.45	41.1	feet.
2,600	1.36	46.4	2.44	42.4	
2,700	1.37	51.4	2.43	47.4	
2,800	1.37	54.4	2.42	50.4	
2,900	1.37	57.1	2.39	53.1	
3,000	1.37	59.4	2.37	55.4	
3,100	1.36	59.8	2.34	55.8	
3,200	1.36	60.1	2.31	56.1	
3,300	1.35	61.8	2.25	57.8	
3,400	1.32	61.6	2.14	57.6	
3,500	1.27	60.4	2.03	56.4	
3,600	1.19	63.1	1.88	59.1	
3,700	1.13	54.4	1.72	50.4	
3,800	1.05	54.8	1.57	50.8	
3,900	0.97	54.4	1.34	50.4	
4,000	0.90	29.6	1.14	25.6	
4,100	0.70	26.4	0.96	22.4	[section at head of pier 45, New York.
4,200	0.49	23.7	0.73	19.7	Latitude, 40° 43′ 37″.8; longitude, 74° 00′ 50″.8. End of

Transverse curves of velocity, and perimeters—Continued.

SECTION XXX.

Distance from Jersey side.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.23	24.6	0.82	20.6	Latitude, 40° 44′ 13″.0; longitude, 74° 01′ 32″.6. Beginning of section at North Second street wharf, Hoboken.
100	0.53	29.1	1.10	25.1	
200	0.71	34.6	1.39	30.6	
300	0.83	37.1	1.65	33.1	
400	0.90	42.6	1.92	38.6	
500	0.92	51.1	2.08	47.1	
600	0.94	46.6	2.15	42.6	
700	0.96	46.8	2.17	42.8	
800	0.97	47.1	2.18	43.1	
900	0.98	47.1	2.20	43.1	
1,000	1.00	47.6	2.22	43.6	
1,100	1.01	48.1	2.27	44.1	
1,200	1.03	50.6	2.29	46.6	
1,300	1.05	49.1	2.30	45.1	
1,400	1.06	49.1	2.31	45.1	Area of section: Flood, 184,798 square feet; ebb, 170,078 square feet.
1,500	1.09	50.6	2.31	46.6	
1,600	1.11	51.1	2.32	47.1	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 1,990 feet.
1,700	1.12	51.6	2.33	47.6	
1,800	1.14	53.1	2.33	49.1	
1,900	1.17	59.1	2.33	55.1	
2,000	1.19	58.8	2.33	54.8	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 2,127 feet; ebb, 1,933 feet.
2,100	1.22	61.6	2.33	57.6	
2,200	1.24	67.6	2.33	63.6	
2,300	1.26	70.6	2.33	66.6	
2,400	1.27	73.6	2.33	69.6	
2,500	1.29	73.6	2.31	69.6	
2,600	1.29	73.6	2.29	69.6	
2,700	1.29	72.1	2.23	68.1	
2,800	1.29	70.6	2.17	66.6	
2,900	1.29	63.6	2.09	59.6	
3,000	1.27	56.6	1.97	52.6	
3,100	1.21	47.1	1.89	43.1	
3,200	1.15	52.6	1.81	48.6	
3,300	1.03	32.6	1.69	28.6	
3,400	0.90	31.1	1.58	27.1	
3,500	0.73	22.6	1.46	18.6	
3,600	0.57	12.1	1.32	8.1	[section at foot of Bank street, New York.
3,680	0.42	11.1	1.16	7.1	Latitude, 40° 44′ 06″.8; longitude, 74° 00′ 45″.4. End of

Transverse curves of velocity, and perimeters—Continued.

SECTION XXXI.

Distance from Jersey side.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.91	4.1	2.07	0.1	Latitude, 40° 44′ 38″.9; longitude, 74° 01′ 24″.4. Beginning
100	1.01	15.6	2.27	11.6	of section at Castle Point.
200	1.01	34.1	2.35	30.1	
300	1.00	38.1	2.37	34.1	
400	0.99	42.1	2.39	38.1	
500	0.96	48.1	2.40	44.1	
600	0.96	51.1	2.40	47.1	
700	0.99	54.1	2.40	50.1	
800	1.00	56.1	2.39	52.1	
900	1.05	58.1	2.37	54.1	
1,000	1.09	59.1	2.36	55.1	
1,100	1.13	63.1	2.35	59.1	
1,200	1.16	67.1	2.35	63.1	
1,300	1.21	74.1	2.35	70.1	Area of section: Flood, 160,530 square feet; ebb, 147,730
1,400	1.24	74.1	2.35	70.1	square feet.
1,500	1.28	74.1	2.35	70.1	Mid-area, or distance, from the origin, of a vertical line
1,600	1.31	75.6	2.35	71.6	which divides the section into two equal areas=1,536 feet.
1,700	1.32	75.1	2.35	71.1	Mid-volume, or distance, from the orign, of a vertical
1,800	1.34	72.1	2.35	68.1	line which divides the volume passing through the section
1,900	1.34	70.1	2.35	66.1	into two equal parts=flood, 1,700 feet; ebb, 1,486 feet.
2,000	1.34	68.3	2.35	64.3	
2,100	1.32	59.3	2.32	55.3	
2,200	1.31	60.1	2.31	56.1	
2,300	1.28	54.1	2.16	50.1	
2,400	1.27	50.3	1.94	46.3	
2,500	1.27	43.8	1.65	39.8	
2,600	1.27	39.1	1.36	35.1	
2,700	1.27	34.1	1.03	30.1	
2,800	1.27	32.6	0.76	28.6	
2,900	1.27	29.1	0.45	25.1	
3,000	1.14	14.1	0.18	10.1	
3,100	0.61	11.3	0.08	7.3	[tion at head of wharf foot of Fourteenth street, New York.
3,200	0.00	10.3	0.00	6.3	Latitude, 40° 44′ 33″.4; longitude, 74° 00′ 43″.4. End of sec-

Transverse curves of velocity, and perimeters—Continued.

SECTION XXXII.

Distance from New York side.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0. 25	13. 4	0. 30	9. 6	Latitude, 40° 44′ 50″.0; longitude, 74° 00′ 40″.2. Section begins at New York side.
100	0. 58	16. 9	0. 69	13. 1	
200	0. 70	18. 4	0. 89	14. 6	
300	0. 83	26. 4	1. 08	22. 6	
400	0. 91	32. 9	1. 25	29. 1	
500	0. 99	34. 9	1. 39	31. 1	
600	1. 07	38. 4	1. 51	34. 6	
700	1. 12	45. 4	1. 67	41. 6	
800	1. 17	45. 4	1. 76	41. 6	
900	1. 24	50. 9	1. 88	47. 1	
1, 000	1. 26	54. 9	2. 01	51. 1	
1, 100	1. 30	58. 9	2. 06	55. 1	
1, 200	1. 33	57. 3	2. 23	53. 5	
1, 300	1. 34	57. 3	2. 29	53. 5	
1, 400	1. 35	57. 3	2. 40	53. 5	
1, 500	1. 37	65. 6	2. 47	61. 8	
1, 600	1. 39	64. 3	2. 53	60. 5	Area of section: Flood, 162,831 square feet; ebb, 148,194 square feet.
1, 700	1. 39	64. 0	2. 56	60. 2	
1, 800	1. 39	65. 3	2. 61	61. 5	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=1,770 feet.
1, 900	1. 39	65. 3	2. 63	61. 5	
2, 000	1. 38	63. 6	2. 65	59. 8	
2, 100	1. 35	63. 6	2. 65	59. 8	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 1,759 feet; ebb, 1,870 feet.
2, 200	1. 34	67. 3	2. 67	63. 5	
2, 300	1. 33	56. 3	2. 67	52. 5	
2, 400	1. 33	58. 7	2. 70	54. 9	
2, 500	1. 31	61. 0	2. 70	57. 2	
2, 600	1. 24	51. 2	2. 65	47. 4	
2, 700	1. 21	37. 8	2. 56	34. 0	
2, 800	1. 17	41. 2	2. 45	37. 4	
2, 900	1. 12	38. 9	2. 25	35. 1	
3, 000	1. 06	36. 9	2. 06	33. 1	
3, 100	0. 99	31. 5	1. 86	27. 7	
3, 200	0. 90	28. 2	1. 64	24. 4	
3, 300	0. 75	16. 3	1. 37	12. 5	
3, 400	0. 66	14. 0	1. 08	10. 2	
3, 500	0. 51	11. 8	0. 79	8. 0	
3, 600	0. 39	9. 0	0. 49	5. 2	
3, 700	0. 20	7. 9	0. 20	4. 1	
3, 800	0. 00	7. 0	0. 00	3. 2	
3, 852	0. 00	5. 0	0. 00	1. 2	Latitude, 40° 44′ 54″.2; longitude, 74° 01′ 29″.6. Section ends at Jersey shore.

Transverse curves of velocity, and perimeters—Continued.

SECTION XXXIII.

Distance from New York side.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.36	12.5	0.37	8.5	Latitude, 40° 45′ 15″.6; longitude, 74° 00′ 30″.2. Section
100	0.52	30.8	0.56	26.8	begins at New York side.
200	0.67	33.3	1.18	29.3	
300	0.79	34.0	1.79	30.0	
400	0.92	34.5	1.88	30.5	
500	1.04	37.3	1.99	33.3	
600	1.14	37.0	2.16	33.0	
700	1.21	36.8	2.25	32.8	
800	1.28	37.3	2.35	33.3	
900	1.35	37.8	2.39	33.8	
1,000	1.38	38.1	2.44	34.1	
1,100	1.42	38.5	2.54	34.5	
1,200	1.45	39.0	2.55	35.0	
1,300	1.47	39.4	2.61	35.4	
1,400	1.49	39.4	2.63	35.4	
1,500	1.52	40.9	2.63	36.9	
1,600	1.54	40.9	2.63	36.9	
1,700	1.55	41.9	2.63	37.9	
1,800	1.55	42.9	2.65	38.9	
1,900	1.55	44.2	2.65	40.2	
2,000	1.55	48.0	2.65	44.0	
2,100	1.52	48.3	2.65	44.3	Area of section: Flood, 161,068 square feet; ebb, 142,200
2,200	1.52	48.3	2.65	44.3	square feet.
2,300	1.49	48.4	2.65	44.4	Mid-area, or distance, from the origin, of a vertical line
2,400	1.49	49.9	2.65	45.9	which divides the section into two equal areas=2,080 feet.
2,500	1.47	51.3	2.65	47.3	Mid-volume, or distance, from the origin, of a vertical
2,600	1.46	50.4	2.65	46.4	line which divides the volume passing through the section
2,700	1.42	49.9	2.65	45.9	into two equal parts=flood, 2,020 feet; ebb, 2,090 feet.
2,800	1.38	50.1	2.63	46.1	
2,900	1.35	50.1	2.58	46.1	
3,000	1.28	50.3	2.49	46.3	
3,100	1.24	47.6	2.39	43.6	
3,200	1.17	46.9	2.25	42.9	
3,300	1.12	44.0	2.15	40.0	
3,400	1.07	41.2	1.98	37.2	
3,500	0.92	32.0	1.79	28.0	
3,600	0.81	23.0	1.58	19.0	
3,700	0.71	21.2	1.34	17.2	
3,800	0.57	18.0	1.13	14.0	
3,900	0.50	13.0	0.94	9.0	
4,000	0.35	10.0	0.70	6.0	
4,100	0.21	10.0	0.47	6.0	
4,200	0.07	6.0	0.19	2.0	
4,300	0.00	5.7	0.00	1.7	
4,400	0.00	5.2	0.00	1.2	
4,500	0.00	4.7	0.00	0.7	
4,600	0.00	4.3	0.00	0.3	
4,700	0.00	4.0	0.00	0.0	[ends at Jersey shore.
4,717	0.00	4.0	0.00	0.0	Latitude, 40° 45′ 36″.0; longitude, 74° 01′ 25″.4. Section

Transverse curves of velocity, and perimeters—Continued.

SECTION XXXIV.

Distance from New York side.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.33	15.9	1.27	12.1	Latitude, 40° 45′ 45″.8; longitude, 74° 00′ 10″.8. Section begins at New York side.
100	0.48	18.0	1.51	14.2	
200	0.64	20.0	1.72	16.2	
300	0.80	22.0	1.94	18.2	
400	0.92	24.0	2.16	20.2	
500	1.04	26.0	2.27	22.2	
600	1.12	32.3	2.46	28.5	
700	1.21	34.1	2.59	30.3	
800	1.29	36.5	2.70	32.7	
900	1.36	37.8	2.75	34.0	
1,000	1.44	38.2	2.75	34.4	
1,100	1.48	39.2	2.79	35.4	
1,200	1.52	39.8	2.79	36.0	
1,300	1.53	40.0	2.79	36.2	
1,400	1.58	40.0	2.81	36.2	
1,500	1.60	40.0	2.81	36.2	
1,600	1.60	40.0	2.81	36.2	
1,700	1.60	40.0	2.81	36.2	
1,800	1.60	40.0	2.81	36.2	
1,900	1.60	40.3	2.81	36.5	Area of section: Flood, 158,200 square feet; ebb, 141,100 square feet.
2,000	1.57	41.0	2.81	37.2	
2 100	1.53	41.5	2.81	37.7	
2,200	1.52	42.0	2.81	38.2	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas=2,277 feet.
2,300	1.52	42.5	2.76	38.7	
2,400	1.48	43.0	2.72	39.2	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts=flood, 2,101 feet; ebb, 2,131 feet.
2,500	1.45	44.0	2.68	40.2	
2,600	1.44	46.0	2.59	42.2	
2,700	1.40	48.2	2.49	44.4	
2,800	1.36	49.2	2.43	45.4	
2,900	1.34	50.1	2.35	46.3	
3,000	1.32	51.0	2.27	47.2	
3,100	1.28	51.0	2.16	47.2	
3,200	1.24	51.0	2.06	47.2	
3,300	1.18	49.0	1.97	45.2	
3,400	1.12	46.0	1.84	42.2	
3,500	1.08	43.0	1.72	39.2	
3. 600	0.96	38.0	1.56	34.2	
3,700	0.88	32.3	1.35	28.5	
3,800	0.72	28.2	1.10	24.4	
3,900	0.52	24.1	0.84	20.3	
4,000	0.32	21.0	0.54	17.2	
4,100	0.00	16.3	0.23	12.5	
4,200	0.00	12.0	0.00	8.2	
4,300	0.00	7.5	0.00	3.7	
4,400	0.00	5.8	0.00	2.0	
4,500	0.00	4.1	0.00	0.4	Latitude, 40° 46′ 07″.6; longitude, 74° 01 01″.6. Section ends at Jersey shore.

Transverse curves of velocity, and perimeters—Continued.

SECTION XXXV.

Distance from New York side.	Flood. Maximum velocity (reduced to mean tide).	Flood. Depth (at standard plane of maximum velocity).	Ebb. Maximum velocity (reduced to mean tide).	Ebb. Depth (at standard plane of maximum velocity).	Remarks.
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.34	15.0	0.74	11.4	Latitude, 40° 46′ 15″.7; longitude, 73° 59′ 42″.8. Section
100	0.49	16.5	1.17	12.9	begins on New York side.
200	0.58	18.0	1.48	14.4	
300	0.71	31.0	1.80	27.4	
400	0.79	32.0	2.01	28.4	
500	0.86	33.5	2.15	29.9	
600	0.92	37.0	2.23	33.4	
700	0.99	37.0	2.29	33.4	
800	1.06	37.5	2.33	33.9	
900	1.13	38.0	2.38	34.4	
1,000	1.19	38.7	2.44	35.1	
1,100	1.25	39.5	2.49	35.9	
1,200	1.31	40.5	2.54	36.9	
1,300	1.34	41.5	2.54	37.9	
1,400	1.35	42.2	2.54	38.6	
1,500	1.38	43.0	2.54	39.4	
1,600	1.40	43.5	2.54	39.9	
1,700	1.40	44.0	2.54	40.5	
1,800	1.40	45.1	2.52	41.5	
1,900	1.40	46.0	2.49	42.4	Area of section: Flood, 161,770 square feet; ebb, 145,462
2,000	1.40	46.5	2.46	42.9	square feet.
2,100	1.41	49.5	2.44	45.9	
2,200	1.42	51.1	2.44	47.5	Mid-area, or distance, from the origin, of a vertical line
2,300	1.42	52.0	2.44	48.4	which divides the section into two equal areas=2,143 feet.
2,400	1.42	53.5	2.42	49.9	Mid-volume, or distance, from the origin, of a vertical
2,500	1.42	54.5	2.42	50.9	line which divides the volume passing through the section
2,600	1.44	54.5	2.33	50.9	into two equal parts=flood, 2,220 feet; ebb, 2,086 feet.
2,700	1.45	54.5	2.33	50.9	
2,800	1.47	53.5	2.33	49.9	
2,900	1.47	48.9	2.31	45.3	
3,000	1.45	44.4	2.24	40.8	
3,100	1.44	41.0	2.20	37.4	
3,200	1.42	38.4	2.16	34.8	
3,300	1.40	38.4	2.12	34.8	
3,400	1.40	33.4	2.12	29.8	
3,500	1.35	28.4	2.04	24.8	
3,600	1.25	27.0	1.96	23.4	
3,700	1.13	27.0	1.89	23.4	
3,800	1.06	17.0	1.80	13.3	
3,900	0.87	17.4	1.72	13.9	
4,000	0.76	18.5	1.57	14.9	
4,100	0.64	17.5	1.32	13.9	
4,200	0.42	16.5	1.06	12.9	
4,300	0.29	5.0	0.64	1.4	
4,400	0.07	4.0	0.32	0.4	
4,500	0.00	4.0	0.00	0.4	[ends on Jersey shore.
4,530	0.00	4.0	0.00	0.4	Latitude, 40° 46′ 38″.9; longitude, 74° 00′ 32″.8. Section

Transverse curves of velocity, and perimeters—Continued.

SECTION XXXVI.

Distance from New York shore.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.50	21.7	1.19	18.0	Latitude, 40° 46′ 35″.7; longitude, 73° 59′ 28″.6. Section begins at New York shore.
100	0.73	24.2	1.53	20.5	
200	0.88	26.7	1.74	23.0	
300	0.96	30.2	1.95	26.5	
400	1.03	33.7	2.09	30.0	
500	1.09	33.7	2.18	30.0	
600	1.17	37.8	2.29	34.1	
700	1.18	37.8	2.34	34.1	
800	1.24	38.8	2.40	35.1	
900	1.25	39.8	2.40	36.1	
1,000	1.28	40.8	2.41	37.1	
1,100	1.31	42.3	2.41	38.6	
1,200	1.32	42.3	2.48	38.6	
1,300	1.32	44.0	2.48	40.3	
1,400	1.32	45.8	2.51	42.1	
1,500	1.32	43.7	2.51	40.0	
1,600	1.32	46.1	2.51	42.4	
1,700	1.32	48.3	2.51	44.6	Area of section: Flood, 155,963 square feet; ebb, 140,393 square feet.
1,800	1.32	50.7	2.51	47.0	
1,900	1.34	53.3	2.51	49.6	Mid-area, or distance, from the origin, of a vertical line which divides the section into two equal areas = 1,956 feet.
2,000	1.37	54.0	2.51	50.3	
2,100	1.37	54.2	2.51	50.5	
2,200	1.39	54.8	2.51	51.1	Mid-volume, or distance, from the origin, of a vertical line which divides the volume passing through the section into two equal parts = flood, 2,063 feet; ebb, 1,974 feet. Elevation of water's surface on flood, 4 feet, and on ebb 0.3 foot above mean low water.
2,300	1.39	55.1	2.51	51.4	
2,400	1.39	54.1	2.48	50.4	
2,500	1.40	54.3	2.48	50.6	
2,600	1.42	50.3	2.45	46.6	
2,700	1.43	48.5	2.43	44.8	
2,800	1.44	46.8	2.45	43.1	
2,900	1.44	44.8	2.40	41.1	
3,000	1.45	42.8	2.38	39.1	
3,100	1.46	36.3	2.36	32.6	
3,200	1.46	30.1	2.31	26.4	
3,300	1.46	30.1	2.29	26.4	
3,400	1.46	25.5	2.21	21.8	
3,500	1.46	23.2	2.18	19.5	
3,600	1.42	23.0	2.07	19.3	
3,700	1.39	20.1	1.96	16.4	
3,800	1.31	16.1	1.80	12.4	
3,900	1.17	10.1	1.52	6.4	
4,000	0.80	7.1	0.98	3.4	
4,100	0.43	5.1	0.54	1.4	
4,200	0.07	4.1	0.11	0.4	
4,208	0.00	4.1	0.00	0.4	Latitude, 40° 46′ 56″.2; longitude, 74° 00′ 16″.2. Section ends on Jersey shore.

Transverse curves of velocity, and perimeters—Continued.

SECTION XXXVII.

Distance from New York side.	Flood.		Ebb.		Remarks.
	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	Maximum velocity (reduced to mean tide).	Depth (at standard plane of maximum velocity).	
	Naut. miles per hour.	*Feet.*	*Naut. miles per hour.*	*Feet.*	
0	0.80	34.5	2.59	30.7	Latitude, 40° 47′ 07″.4; longitude, 73° 59′ 08″.4. Section
100	0.92	34.0	2.60	30.2	begins at New York side.
200	0.97	37.0	2.60	33.2	
300	1.04	39.7	2.60	35.9	
400	1.08	42.5	2.58	38.7	
500	1.12	42.5	2.58	38.7	
600	1.16	43.8	2.58	40.0	
700	1.19	45.1	2.58	41.3	
800	1.21	46.5	2.58	42.7	
900	1.26	47.2	2.58	43.4	
1,000	1.29	49.0	2.58	45.2	
1,100	1.34	50.0	2.58	46.2	
1,200	1.40	51.5	2.58	47.7	
1,300	1.40	52.0	2.58	48.2	
1,400	1.40	52.6	2.58	48.8	
1,500	1.40	53.0	2.58	49.2	
1,600	1.40	53.7	2.58	49.9	
1,700	1.40	54.5	2.58	50.7	
1,800	1.40	53.0	2.58	49.2	Area of section: Flood, 158,707 square feet; ebb, 142,379
1,900	1.40	53.2	2.58	49.4	square feet.
2,000	1.40	53.5	2.58	49.7	Mid-area, or distance, from the origin, of a vertical line
2,100	1.40	50.0	2.58	46.2	which divides the section into two equal areas=1,683 feet.
2,200	1.40	49.0	2.58	45.2	Mid-volume, or distance, from the origin of a vertical
2,300	1.40	48.1	2.58	44.3	line which divides the volume passing through the section
2,400	1.40	47.5	2.55	43.7	into two equal parts=flood, 1,706 feet; ebb, 1,533 feet.
2,500	1.36	44.5	2.51	40.7	
2,600	1.33	35.5	2.51	31.7	
2,700	1.29	35.0	2.48	31.2	
2,800	1.26	34.5	2.47	30.7	
2,900	1.26	29.7	2.45	25.9	
3,000	1.21	28.0	2.45	24.2	
3,100	1.19	26.7	2.45	22.9	
3,200	1.19	25.5	2.43	21.7	
3,300	1.15	22.5	2.32	18.7	
3,400	1.12	22.0	2.32	18.2	
3,500	1.08	20.0	2.31	16.2	
3,600	1.07	19.2	2.26	15.4	
3,700	1.03	18.5	2.19	14.7	
3,800	0.94	14.5	2.13	10.7	
3,900	0.85	17.2	2.00	13.7	
4,000	0.75	12.2	1.54	8.4	
4,100	0.58	9.0	1.26	5.2	
4,200	0.42	4.2	0.80	0.4	[ends at Jersey shore.
4,297	0.00	4.2	0.00	0.4	Latitude, 40° 47′ 27″.3; longitude, 73° 59′ 57″.8. Section

APPENDIX No. 11.

REPORT CONCERNING THE LOCATION OF A QUAY OR PIER LINE IN THE VICINITY OF THE UNITED STATES NAVY-YARD AT NEW YORK.

DEAR SIR: I beg leave to present the results of a little study that we have made of the movements of the currents of the East River, near the navy-yard, and to suggest the location of a quay or pier line that would improve navigation in this neighborhood.

In making our study of the currents we have followed much the same plan that we adopted in locating the South Boston sea-wall in 1861, except that more recent experiences in San Francisco, New York, and elsewhere have led to some improvements in the arrangement of our stations and in the reduction of our observations. We have determined the transverse curves of velocities and the profiles of corresponding cross-sections of the river, so as to ascertain the degree of accommodation which the channel offers to the flood and ebb respectively, and we have plotted the directions of the currents. Unlike the case presented at Boston, the comparisons of profile and transverse curves of velocity show that the channel, in its form, does not reflect the action of one stream (either ebb or flood), but its unyielding bed, near the navy-yard and elsewhere in the East River, controls the curves and influences the velocities of the currents, both of ebb and flood. The comparisons, however, indicate that artificial control at some points may prove beneficial to the navigation, by diminishing the races and eddies that are due to the present irregular borders of the river.

We have designed, and in a measure succeeded in, representing graphically the elements of our study (see illustration No. 23); but that nothing may be wanting we have added to this report the tables from which the diagrams are plotted.

Before commenting upon the details of these diagrams, I must call your attention to a distinction between Nos. 1 and 2, and those marked A, B, and C. In the former, for the sake of conformity with the work done by the United States commission on the pier-lines of Brooklyn, we have reduced the velocities by ratios, adopted by said commission, based upon the rise and fall of tide; but in the latter, by volumes actually measured at Wall-street section.

We have preferred the reduction by volume rather than that by rise and fall of tide, because the currents being of the "*interference*" order (*i. e.*, an interchange between two tidal systems—that of Long Island Sound and the Sandy Hook entrance) they are *out of register* with the local rise and fall; and it has seemed to us that nothing but a reduction to *mean volume by actual gauging of ebb and flood currents* can bring observations in different sections of our work into their natural conformity. We have used the result of the gauging at Wall street, which gave us 268,333 cubic feet per second at maximum current of mean tides. Whether the filling and draining of the space between Wall street and the navy-yard would augment or diminish this volume we are unable to say until further gaugings are made. Whichever way it counts, it will affect the velocities only 2 per cent. at the utmost. If we consider this additive both to flood and ebb, we still find the results of the commission largely in excess of ours.

We have regarded the velocity in the East River as a function of the slope or difference of level between the water surfaces of the harbor and sound at each instant of time, and it is this slope which I have recently desired instructions to determine for different phases and declinations of the moon in connection with current-observations, in order that we may compute tables of velocity for the use of navigators.

The *changes* in the areas and perimeters of the sections are so small from springs to neaps that I expect only to have to determine a single coefficient, which, multiplied into the square root of the slope, shall give the velocity of the current for any designated reach of the river.

Diagram A or B is constructed from observations at three sections, at each of which the currents were simultaneously observed at three points at the time of maximum. These three points and the

two ends of the section which we either called zero or (if a smooth wall) estimated for, gave us the means of constructing a pretty accurate curve. This curve, being the velocity of the upper 10 feet stratum (10 feet being the draught of our log), was then corrected by applying such a coefficient as should provide for the passage, by such a curve, of the *standard mean volume.* Our diagram, then, represents the average movement from surface to bottom at the moment of maximum flood or ebb of an ordinary tide.

Diagram C is simply a combination of A and B, designed to show how well we have, upon the whole, filled our quay to the compromise lines of ebb and flood.

Our quay-line proposed is the arc of a circle of 3,500 feet radius which passes through the head of the Williamsburg Ferry berth, and through a point 40 feet within the salient angle of the wharf at the western extremity of the cove occupied in part by the cob-dock. This salient angle, to which we have just referred, ought to be cut off; it offers too great an obstruction to the ebb, causing eddies which bewilder the navigation.

Supposing the cob-dock removed, the cove within our proposed quay would have an area of about 100 acres, and would accommodate, if excavated, as many first-class ships, closely moored, or twice as many miscellaneous vessels.

Of course, a nearly continuous quay-wall along our proposed line would best favor navigation up and down the river, and in case this were decided upon, a proper place for the entrance to the navy-yard would be found 800 to 1,100 feet from the westerly end of the proposed wall. An opening here of 250 feet, which would be greater than that of the Atlantic Dock, would not, we think, give rise to eddies or be at any time difficult of access, and we should prefer to double this width rather than provide a second opening near the eastern extremity of the arc we have drawn.

If, instead of a nearly continuous quay, it should be decided to adopt our line as a *pier-line* in the ordinary sense, *i. e.*, the limit of wharves, we still think that an improvement of navigation would be effected when these wharves should all be built to the full extent, but we should wish to limit the width of the slips to the practical minimum for first-class accommodation—say 150 to 200 feet in the clear.

We have made some calculations to ascertain how the velocities in the axis of the stream and the forms of the transverse curves will be affected by the presence of such a quay as we suggest (see table of Section VIII). The general premise for such a calculation would be this: *Where the encroaching wall is to lie parallel to the course of the existing current, it will not alter the form of the transverse curve of velocities but increase these velocities by so much as may be due to the moving volume cut off by said wall.* Our case is not precisely this, but would amount to no more if allowance is made for the irregularities of the shore which now exist. Only one section—VIII—is affected by the wall appreciably, and this change is too small to be exhibited upon the diagrams.

The observations which form the basis of this report are a part of the general study of the East River, which we have in hand. This study has been under my direction, but the field-work has fallen mostly upon others. Mr. F. F. Nes, with the steamer Arago, Mr. H. L. Marindin, with the schooner Bowditch, and Mr. John B. Weir, with the schooner Hassler, formed the working force, and their records of simultaneous work have been deposited in the archives. The computations which are appended are the work of Mr. Weir, to whom I am also indebted for many suggestions about the plans presented.

Very respectfully, yours,

HENRY MITCHELL,
United States Coast Survey.

CARLILE P. PATTERSON,
Superintendent United States Coast Survey.

Section No. VI.—EAST RIVER, NEW YORK.

Time after transit: Flood, $6^h\ 30^m$; ebb, 0^h.

Distance from Brooklyn side.	Observed maximum velocity.		Observed velocity reduced to mean maximum.		Mean maximum reduced to accepted tracing.		Remarks.
	Flood.	Ebb.	Flood.	Ebb.	Flood.	Ebb.	
			Coef.=0.96	*Coef.*=0.83	*Coef.*=1.43	*Coef.*=1.23	
0	0.00	3.36	0.00	2.78	0.00	3.41	Brooklyn end of cable-crossing.
100	0.98	3.48	0.94	2.88	1.34	3.54	
200	1.43	3.55	1.37	2.94	1.95	3.61	
300	1.88	3.59	1.80	2.97	2.57	3.65	
400	2.47	3.60	2.37	2.98	3.38	3.66	
500	3.10	3.60	2.98	2.98	4.26	3.66	
600	3.60	3.60	3.45	2.98	4.93	3.66	Area of section at time of maximum: Flood, 58,503 square feet; ebb, 54,657 square feet.
700	3.77	3.55	3.61	2.94	5.16	3.61	
800	3.82	3.49	3.66	2.87	5.23	3.53	The accepted tracing referred to is that adopted by the commissioners on the pier-lines of Brooklyn.
900	3.78	3.40	3.62	2.82	5.17	3.46	
1,000	3.67	3.30	3.53	2.73	5.04	3.35	
1,100	3.49	3.20	3.35	2.65	4.79	3.25	
1,200	3.38	3.10	3.24	2.57	4.63	3.16	
1,300	3.07	2.95	2.94	2.44	4.20	3.00	
1,400	2.85	2.72	2.73	2.25	3.90	2.76	
1,408	2.83	2.70	2.59	2.24	3.70	2.75	Pier 54, New York.

John B. Weir, *Computer.*

Section No. VII.—EAST RIVER.

Time after transit: Flood, $6^h\ 30^m$; ebb, 0^h.

Distance from cob-dock.	Observed maximum velocity.		Observed velocity reduced to mean maximum.		Mean maximum reduced to accepted tracing.		Remarks.
	Flood.	Ebb.	Flood.	Ebb.	Flood.	Ebb.	
			Coef.=0.93	*Coef.*=1.03	*Coef.*=1.43	*Coef.*=1.23	
0	0.00	0.00	0.00	0.00	0.00	0.00	Cob-dock face (old line).
100	0.08	0.00	0.07	0.00	0.10	0.00	
200	0.19	0.03	0.17	0.03	0.24	0.03	
300	0.35	0.06	0.32	0.06	0.45	0.07	
400	0.58	0.13	0.53	0.13	0.75	0.15	
500	0.89	0.20	0.82	0.20	1.17	0.24	
600	1.33	0.50	1.23	0.51	1.75	0.62	
700	1.82	0.78	1.69	0.80	2.41	0.98	
800	2.20	1.15	2.04	1.18	2.91	1.45	Area of section at time of maximum: Flood, 94,440 square feet; ebb, 88,512 square feet.
900	2.45	1.57	2.27	1.60	3.24	1.88	
1,000	2.70	2.00	2.51	2.06	3.58	2.53	The accepted tracing referred to is that adopted by the commissioners on the pier-lines of Brooklyn.
1,100	2.88	2.31	2.67	2.38	3.81	2.80	
1,200	3.00	2.60	2.79	2.67	3.98	3.28	
1,300	3.08	2.75	2.86	2.83	4.08	3.48	
1,400	3.07	2.81	2.85	2.89	4.07	3.55	
1,500	2.94	2.81	2.73	2.89	3.90	3.55	
1,600	2.65	2.78	2.46	2.86	3.51	3.51	
1,700	2.29	2.67	2.12	2.75	3.03	3.38	
1,800	1.78	2.50	1.65	2.57	2.35	3.16	
1,900	1.35	2.30	1.26	2.37	1.91	2.91	
2,000	0.85	2.05	0.79	2.11	1.12	2.50	
2,100	0.45	1.65	0.41	1.69	0.58	2.07	
2,200	0.05	1.13	0.04	1.16	0.05	1.42	
2,300	—0.25	0.40	—0.23	0.41	—0.32	0.50	
2,330	—0.35	0.17	—0.32	0.17	—0.45	0.20	Corner of pier, Corlear's Hook.

John B. Weir, *Computer.*

SECTION NO. VIII.—EAST RIVER, NEW YORK.

[Velocities in nautical miles per hour.]

Distance from Williamsburg side.	Observed maximum velocity.		Observed velocity reduced to mean maximum.		Mean maximum reduced to accepted tracing.		Maximum velocity after reducing section by new pier-line.		Remarks.
	Flood.	Ebb.	Flood.	Ebb.	Flood.	Ebb.	Flood.	Ebb.	
Feet.			*Coef.*=0.93	*Coef.*=0.90	*Coef.*=1.43	*Coef.*=1.23	*Coef.*=1.03	*Coef.*=1.03	
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
100	1.57	0.25	1.45	0.23	2.02	0.28	1.49	0.23	
167	1.85	0.40	1.72	0.36	2.45	0.44	1.77	0.37	
200	1.96	0.50	1.82	0.45	2.60	0.55	1.87	0.46	
300	2.10	0.75	1.95	0.68	2.79	0.84	2.00	0.70	The last two columns are obtained by multiplying the two columns under the head of "Observed velocity reduced to mean maximum" by the coefficient 1.03. They represent the conditions that will obtain after the construction of a proposed quay.
400	2.28	1.00	2.11	0.90	3.02	1.11	2.17	0.92	
500	2.38	1.30	2.22	1.17	3.16	1.44	2.28	1.20	
600	2.49	1.66	2.31	1.49	3.30	1.83	2.37	1.53	
700	2.55	2.00	2.37	1.80	3.39	2.21	2.44	1.85	
800	2.61	2.45	2.42	2.20	3.46	2.70	2.49	2.26	
900	2.67	2.90	2.48	2.61	3.55	3.21	2.55	2.68	
1,000	2.59	3.26	2.40	2.93	3.43	3.60	2.47	3.01	
1,100	2.57	3.45	2.39	3.11	3.42	3.83	2.46	3.20	
1,200	2.43	3.45	2.25	3.11	3.22	3.83	2.31	3.20	The "accepted tracing" referred to is that adopted by the commissioners on the pier-lines of Brooklyn.
1,300	2.25	3.33	2.09	3.00	2.99	3.69	2.15	3.09	
1,400	2.02	3.12	1.87	2.81	2.67	3.46	1.92	2.89	
1,500	1.75	2.80	1.62	2.52	2.32	3.10	1.66	2.59	
1,600	1.48	2.50	1.37	2.25	1.96	2.77	1.41	2.31	
1,700	1.05	2.10	0.97	1.89	1.39	2.32	0.99	1.94	
1,800	0.70	1.60	0.65	1.44	0.93	1.77	0.66	1.48	
1,900	0.35	0.98	0.32	0.88	0.46	1.08	0.33	0.90	
1,990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

JOHN B. WEIR, *Computer.*

APPENDIX No. 12.

WASHINGTON, D. C., *January* 14, 1876.

DEAR SIR: I submit the following review of the characteristics of the South Pass as about all that I have gleaned thus far from a study of Mr. Marindin's excellent survey. My work is, however, by no means finished, and what I have to say now is confined strictly to the main body of the stream, exclusive of its upper and lower entrances.

The sheets examined extend from the little settlement near the head of the pass to the light-house near the mouth, about eight and a half miles, measured along the course of the stream. In this distance the pass makes two long bends to the westward of its general course, with a short reverse curve between them. I divide the pass into two portions, one embracing the space above Grand Bayou, the other the space below this offset.

The upper division has a radius of curvature of about four and a quarter miles, and extends through an arc of about 45°, while the lower division has a radius of curvature of about eight and three-quarter miles, and extends through an arc of about 29°.

The mean width of the upper division (exclusive of the enlargement at the opening of Grand Bayou) is 748 feet, with 1,085 and 543 feet as the extreme limits. The lower division has a mean width of 624 feet, with extremes of 849 and 504 feet. Throughout both the upper and lower divisions 30 feet of water may be carried along the channelway, while in one case the mean channel-depth exceeds 45 feet, and in the other is 35½ feet. The channel-depth most frequently met with is, in the upper division 47 feet, and in the lower division 37 feet.

In straight reaches the profiles of the cross-sections are pretty well represented by arcs of circles, and the areas of these sections do not differ largely from segments of which the widths from shore to shore are chords. Mr. Hilgard has suggested that a semi-ellipse from the ordinates of which a constant has been subtracted will better conform to the profile in most cases where the river has little or no bend. This appears to be so, judging from the boldness of the banks near the water-line.

The economical section would of course be a semicircle, could the material forming the banks be sustained. As it is, I find no profile of section more than 36° of arc, and the exceptional steepness of the bank near the water-line, to which I have above referred, seems to be due to the sustaining influence of vegetation.

The characteristic profile of the pass in either division has its greatest depression nearer one shore (the concave) than the other, and because of the steepness of the banks near the water-line this characteristic profile will not conform to the parabolic curve as it usually does where a stream meanders through yielding material.

I hope to find, before I have exhausted my own resources in this study, that I can state the position of the maximum ordinate in the characteristic section as a function of the radius of curvature of the river's course.

The narrowest portion of the river is found midway in each of the divisions I have taken, and is, of course, the straightest reach. Here I looked for my economical type, as Professor Peirce had suggested. In the upper division the narrow reach has a sectional radius of 896 feet, with a chord (width at surface) of 562 feet. In the lower division the narrow reach has a radius of section of 830 feet, a chord of 508 feet, an arc of 35° 38¼′, a perimeter of 516 feet, a versin. of 39.8, and an area of section (observed) of 13,500 square feet.

One may admit that an obstruction may not only widen the stream, but ultimately enlarge its sectional area, although paradoxical. If, for instance, a snag should induce a bank to form in the middle of our economical section, an enlargement must take place not only to the original dimensions, but to such greater dimensions as may counterbalance the friction due to the relatively lengthened perimeter, which a departure from the circular arc has necessitated.

There are many of our sections which increase in area as they depart from the circular form, and I have concluded that the explanation above given must answer for their behavior very often, although at great bends, where the stream is eating in upon the concave bank, we may expect this enlargement as a transient condition for the most part.

The repeated surveys show that the sections change from time to time, but these surveys do not furnish enough data to establish the law of variation in the relations of width and depth. I suggest, however, the following rules, which may cover not only the changes of a single section, but those observed in passing from section to section where the course of the stream does not materially change.

1. *The area of the section varies with the cube root of the width* (perimeter, more strictly).
2. *The square root of the mean depth varies with the area of the section.*
3. *For the minimum width between natural banks the mean depth is to the channel-depth as* 7 : 10.

If the natural banks should be replaced by fascine mattings or a revetment of quarry-chips say for one-quarter of the profile extending from either side, the coefficient of resistance would be largely increased and an augmentation of the channel-depth secured. We have no determinations of this coefficient on an adequate scale to be trusted in this case, but, from the Darcy-Bazin* experiments and from information furnished me by yourself relative to the retard of ships in different conditions of foul bottom, I venture to say that the channel-depths (varying with the squares of the axial velocities) might be augmented ten per cent. by the introduction of fascine revetments as above mentioned.

I should have said in its place that the rules I have given for the variations of depth, width, and section are deduced from the ordinary formula for running water, regarding discharge and slope as constants.

In my study of the observed sections, I do not depend upon a single cross-line of soundings in any case, but upon groups of these covering long reaches.

I confess I am disappointed so far in my efforts to reach generalizations, but if you think there is anything practically useful in the above or anything that would be suggestive of better things, I would like to have copies sent to Captain Eads and General Comstock, who may give us further hints in return.

Very respectfully, yours,

HENRY MITCHELL,
United States Coast Survey.

C. P. PATTERSON,
Superintendent Coast Survey.

---

* Recherches Experimentales sur L'Ecoulement de L'Eau dans les Canaux decouverts.

APPENDIX No. 13.

ON MARINE GOVERNORS.

OCTOBER 25, 1875.

MY DEAR SIR: In response to your request for a discussion on the subject of marine governors, which will be of service in determining the merits of devices submitted to you from time to time, I respectfully present the following paper:

MARINE GOVERNORS.

In order to discuss this subject intelligently, requires at the outset an investigation of the manner in which a governor should act, in order to regulate the speed of a marine engine to the best advantage; we may then compare the different types of governor, on the basis ascertained, and a place may be readily assigned to any particular apparatus under consideration.

In smooth water, the resistance to the propelling device is substantially uniform, and no governor is needed; but when the vessel is running directly or obliquely across waves of considerable height, the propeller is uncovered to a greater or less extent by the motion of the vessel or water, or both, and the resistance offered by the fluid fulcrum, being constantly modified, causes the sudden changes in the speed of the engine, known as racing, with the attendant jars to vessel and machinery. The difficulty may be often met in government and other steamers, where time is no object, by running the engines very slowly, so that the speed, when quickened, will not be sufficient to cause injury. By this method of working, most vessels could dispense with the use of a governor, and on any vessel the kind of governor employed would be of little consequence; with merchant-steamers, however, it is desirable, and in making port, or an offing, sometimes necessary, to urge the engine to the highest speed consistent with safety. As it is only under such circumstances that a governor is truly tested, the discussion will be based on such conditions. The problem resolves itself then into obtaining as much speed as possible under adverse circumstances. Whatever that speed may be, it will be nearly uniform, from one moment to another, the mass of matter in the vessel tending to steady the motion from sea to sea; therefore the propeller, which imparts the motion, should be revolved uniformly or substantially so. This consideration alone shows the defects of any system whereby steam is shut off suddenly, either by hand or governing devices, when racing commences, or the position of vessel changes, so as to make racing probable. A spasmodic regulation of this kind cannot keep the speed of the propeller uniform, and the immersed portion of blades must actually drag at times, and resist the progress of the vessel. It follows then that the pressure on the engine-piston must be modified at all times gradually to suit the resistance, so that the rotary and progressive motions will be substantially uniform, and the immersed portions of blades never drag, but propel at all times. It only remains to ascertain what means shall be employed in the construction of the governor to cause the pressure on engine-piston to be varied with the change of resistance, and thus produce a uniform speed of propulsion. Evidently, we may employ the well-known way, and utilize the first changes of speed caused by the changes of resistance to regulate the throttle-valve to suit the resistance.

It has, however, been the endeavor of many inventors to (as it has been expressed) *anticipate* the change of speed by operating the throttle-valve by mechanism governed by the pitching of the vessel, or by the height of the water in relation to the propeller. It is evident that no device can anticipate the change in resistance, and yet regulate in *proportion* to such change. The governor must either shut off steam for a comparatively small movement of the vessel when the propeller will drag in many cases, or the closing of the throttle must be proportionate to the change in the resistance, in which case the change will be felt as quickly as by any other device, and the governor can at the best only act *coincidently* with the changes of resistance and not anticipate them. It is,

however, by no means easy to arrange a mechanism operated by the degree of submersion of the propeller so that it will be influenced by all the changes of condition and thereby regulate the throttle-valve to perfectly prevent changes of speed.

In the first place, the degree of submersion is not a perfect index of the degree of resistance. It is considered as established that in wave motion each particle of water moves in a circle with a diameter equal to the depth of the wave, so the intensity of the reaction must be varied by the various changes in the velocity of the particles of water as they regularly advance and recede, as well as rise and fall. Again, in some cases the crest of a wave may completely envelop the propeller, and yet the mass of water directly behind the latter not be sufficient to give the maximum resistance. Any governor, then, which depends simply upon the degree that the vessel pitches, or even upon the degree of submersion of propeller, is not influenced by all the conditions. What is wanted is the actual pressure of water against the propeller-blades. It is not certain that any device for measuring the pressure, located where it must needs be, forward of the propeller, will accurately indicate the pressure behind the blades. Again, to secure uniformity of speed would require that some steam be admitted, even if the propeller were entirely uncovered, leaving only frictional resistances to be overcome. So the degree of throttle-opening should not be accurately proportioned to the height of the water. This is true for another important reason also, viz, that the more the steam is throttled the more difference in pressure there would be on the two sides of the throttle-valves, and the more rapidly would a given quantity of steam flow through a given opening.

It is thought, therefore, that it would be very difficult to make this form of governor regulate the speed with great exactitude; but inasmuch as it is influenced by the principal one of the changes of condition, viz, the pressure of water at the stern, it should operate to prevent any severe racing. The pneumatic governor on this principle is now pretty well known, and is said to give good satisfaction. In this arrangement the water under the ship's stern compresses air in a chamber of which the changes in pressure are transmitted through a pipe to another chamber containing a diaphragm, which operates the throttle-valve. This plan graduates the movement of valve to the fluid-pressure at the stern. It is therefore far superior to hand-regulation or any device which simply shuts off steam. When the fluid falls below a certain point, or the plane of the vessel's deck is changed in relation to the horizon, as in such cases to prevent racing, the throttle must be closed when the propeller is only partially uncovered, and therefore capable of doing some work, and a loss of speed will result—first, by not permitting the engine to do all it can with safety, and, second, by the drag of the propeller when the speed of same falls below that of the vessel.

A governor operated directly by the pitching of the vessel, either directly by a heavy pendulum, as has been proposed, or indirectly by more intricate devices, has still another defect, for a vessel may lie horizontally on the crest of a long wave with the propeller but partially submerged, when, the throttle-valve being open, the engine would race; while the next moment, as the bow dipped, the governor would shut off steam and slow the propeller just as it became submerged, and thereby stay the vessel's progress. The pendulum plan would have the advantage of one for instantly shutting the valve when a certain angle of pitch was obtained, as it would graduate the speed in some measure to the degree of pitch, while the arrangement for suddenly shutting valve could not be regulated to entirely prevent racing without reducing the mean speed of the vessel to such an extent that it would be questionable if it were not as well to obtain the same speed by permitting the engine to run throttle down without using the governor.

Recurring to the original proposition that the speed of engine should be practically uniform, which requires that the supply of steam be regulated to correspond to the resistance offered to the propeller, it may again be observed that such resistance can be measured by no instrument as accurately as by the propeller itself. Ordinarily, the pressure on the piston is equilibrated by the sum of the resistances forming the load and the speed becomes uniform; then the slightest change of load, by the operation of well-known laws, instantly produces a change of speed which will cause a good centrifugal governor to regulate the throttle-valve so as to prevent extreme changes and bring the engine back to the normal speed. A governor operating by change of speed attains the desired end with almost absolute perfection, as advantage is taken of every condition causing

variation, which, it appears, is practically impossible with other systems. It is true that changes of speed are employed to produce a substantially uniform speed, but there is no inconsistency in this, as interested inventors would make it appear. It is the way of the world. All direct purposes and undertakings are accomplished by making adjustments to suit certain indications. The steersman shifts his rudder when the vessel begins to fall off her course, and the best wake is not absolutely straight. A good steersman keeps a practically straight wake by quickly making adequate correction when the vessel changes her course, and a good governor, in like manner, quickly corrects a change in speed. It is surprising how slight a change will practically answer to accomplish the purpose. Successful regulation of engines used for manufacturing purposes has been obtained, where, for instance, an increase of a single revolution in speed of engine would throw the shuttles out of the loom, or do some other damage.

Engines developing twenty horse-power may be suddenly loaded to two hundred horse-power with no change of speed which can be detected by the eye by watching revolving parts. Marine governors can be made upon the same principles, and need only close attention to the details adapting them for the new service to operate exactly as well.

A brief attention to the points necessary to cause a governor to operate in the way mentioned will be interesting in this connection. The simple form of the conical pendulum governor, in which centrifugal force simply lifts the expanding balls, is not generally used at present, as such a governor requires to be large and heavy to obtain the proper surplus of power. Modern governors are generally run at high speeds, whereby considerable power is obtained with light-moving parts. The centrifugal force varies as the square of the angular velocity, so if the governor be so arranged that the separation of the balls is employed to lift a dead weight, or overcome the corresponding resistance of a spring, a higher speed than that for an ordinary conical pendulum will be required and the apparatus have power to move the governor valve with a slight change of speed. If it were necessary in a given case that the maximum variation of speed be less than 5 per cent., and the valve required a force of 1 pound to move it, the safest plan to secure perfect regulation would be to load the governor, so that at normal speed it would support a weight of 30 pounds, in which case an increase of speed of 5 per cent. would increase the lifting power 10¼ per cent. and leave upward of 3 pounds surplus to move the valve, which evidently would be sufficient to shut it instantly, probably before the engine had completed a single revolution. Ordinarily, however common, the change in speed would be gradual, and as soon as it became sufficient to cause the difference in centrifugal force of 1 pound the valve would begin to close or open gradually, and the speed be regulated much within the extreme limits of 5 per cent. The extreme variation would only take place when the load was changed suddenly, and then would be corrected at once. A screw or turbine-wheel operating upon a fluid with the reaction lifting a weight or compressing a spring, is another form of governor which will accomplish the same results, and may more readily be made isochronous, or have exactly the same rate of speed for all practical loads and positions of the throttle-valve. The conical pendulum changes the rate of speed for different positions of the balls, and though this variation is less in more modern high-speed varieties, some complications are required to entirely preserve it. The differences in rates of speed for different loads are too slight, however, to be considered in a marine governor, and either form of revolving governor may readily be made to maintain the average speed within the limits mentioned. A good high-speed governor is so sensitive that on a single engine it will open the valve a little every time the engine passes her center, and close it again during the stroke, thus forming a kind of cut-off.

For marine governors it is necessary that the resistance in all cases be furnished by springs, as the vertical action of weights is disturbed by the motions of a vessel. To obviate this, it has been proposed to hang an ordinary centrifugal governor in gimbals like a compass; but this is unnecessary, as the spring resistance is entirely practical and much simpler. There is another form of revolving governor, in which a shaft revolved by the engine supports a heavy fly-wheel free to turn thereon. The fly-wheel carries fans to create resistance from the air and receives motion from its shaft through a spring. Included plans or equivalents are provided to transmit the turning or angular movement of the wheel in relation to the shaft to the governor-valve. In the normal condition, the spring is compressed to correspond to the resistance of the vanes, and the throttle-valve

is open. When the engine races the spring is suddenly wound up to a greater extent and the angular movement of shaft in wheel shuts the throttle-valve, but as soon as the speed falls below that of the fly-wheel the valve is opened. This is a heavy apparatus, but with sufficient surplus power will prevent racing.

In another governor, a small engine is kept running at a constant speed, and a pulley on the shaft of same is operated by main engine. The small engine acts the fly-wheel, in the previous example, and the governor-valve is operated in a similar manner, when any difference occurs between speeds of main-engine pulley and that of small engine. This seems like a simple, efficient arrangement, but in practice it has been found especially liable to corrosion, so that the small engine works unsteadily when started after a long period of disuse. Any revolving governor necessitates the use of an operating belt or equivalent, which is inconvenient, and is avoided in governors operated by the pitching of the vessel or the pressure of the water astern; but a belt is so well known by all mechanics, that it should not be omitted for a less familiar arrangement if the latter be at all liable to derangement. An incredible amount of thought and labor has been expended on the subject of marine governors, even by persons not at all familiar with the details of steam-machinery.

It would seem to be not uncommon for persons to occupy themselves during a sea-voyage in designing something to prevent the racing, which has perhaps so affected their rest and comfort, and often each will endeavor to bring in some features with which he is so especially familiar. For instance, it has been proposed to use the regular movement of a clock to produce regularity in the movements of the engine; and one person, without apparently being aware that Watts's governor was but a form of the pendulum, which could be readily modified to adapt it for marine purposes, actually pressed into notice, with great zeal, an enlarged marine-clock movement, adapted as a governor in the following manner: A strong escapement-wheel was given a tendency to revolve rapidly by a friction arrangement operated by the engine. The speed of escapement-wheel was regulated by the usual pallets, lever, balance-wheel, and retracting spring, of proper size. By a kind of differential arrangement the motion of escapement-wheel was transferred to and *opened* the throttle-valve partially at every beat, while a connection with engine *closed* the valve somewhat at every stroke. At normal speed, the opposing motions neutralized each other; at higher speed, the movement from engine predominated and closed the valve; while at slower speed the escapement-movement was the more rapid and opened the valve. During the trial of the apparatus on a land-engine the noise from the escapement could be heard a long distance, and the parts of same suffered rapid destruction.

It has also been proposed to use the motion of the ship, or of the waves in relation thereto, to close an electric circuit by which, through an electro-magnet, a small valve would be so operated and admit steam to a piston which would move the throttle-valve. This form of governor would necessarily act to quickly close or open the throttle-valve instead of graduating the movement to the change of resistance, as in the air and pendulum governors above described, which derive their action from similar initial changes of condition.

In conclusion, it appears from our investigations that the best governors for marine engines are those operated by changes of speed, as such are accurately influenced by all the changes of condition. Of these, the conical pendulum form, or that in which a fluid is displaced by a screw or turbine, will, when resistance for same is furnished by springs of sufficient strength to necessitate high speed, give the most satisfactory results. A marine governor, in which the opening of valve is graduated by the pressure of water at the stern, may be considered next best, and, well designed, will give good practical results. Governors acting by the pitching of the vessel are undesirable, not being influenced by all the conditions. Of this class of governor the pendulum form, which graduates the movement of valve according to the degree of pitching movement, is the better. In general, any governor which opens and closes throttle-valve to the full extreme permitted without graduating the movement to the resistance, is undesirable.

In determining the merits of a governor of either class practical considerations should have great weight, and as a marine governor is, in many places, not used for months, and, by chance, even years, and is all the time liable to corrosion from the effects of the sea air, any arrangement which will best keep in order under such conditions is, other things being equal, the best for practical use. A governor, then, in which the principal parts are inclosed in a case and run in oil, has certainly many advantages.

The space occupied, simplicity of construction, and accessibility of parts, are all points to be given due consideration. Any delicate apparatus requiring technical attention is undesirable, as there is always a great deal to be attended to when the use of a marine governor is necessary, and no devices should be employed which would not be thoroughly understood by members of the engineer force competent to manage the machinery during the disability of the officer in charge.

It may properly be mentioned in this connection that no governor can regulate speed correctly when the steam-chest is very large, or, in general, when there is a very considerable space between the throttle and main valves, as the steam contained in such place will keep the engine in motion after throttle-valve is shut and must be supplied again when throttle-valve is opened, thereby preventing the increased pressure from promptly reaching the piston. On land-engines, the action is best prevented by causing the governor to regulate the cut-off direct; but it is unnecessary to use such a complex apparatus on shipboard, as a less accurate regulation will answer. The intermediate receivers of compound engines have also been mentioned as causing difficulties in regulation; but of late it has been found that a quick-acting governor, of ample power to move valve for slight changes of speed, will control either single or compound engines within limits desired, unless the spaces are unusually large.

Very respectfully,

CHARLES E. EMERY,
Consulting Engineer, United States Coast Survey.

C. P. PATTERSON,
Superintendent United States Coast Survey.

APPENDIX No. 14.

NOTE ON THE THEORY OF THE ECONOMY OF RESEARCH, BY ASSISTANT C. S. PEIRCE.

When a research is of a quantitative nature, the progress of it is marked by the diminution of the probable error. The results of non-quantitative researches also have an inexactitude or indeterminacy which is analogous to the probable error of quantitative determinations. To this inexactitude, although it be not numerically expressed, the term "probable error" may be conveniently extended.

The doctrine of economy, in general, treats of the relations between utility and cost. That branch of it which relates to research considers the relations between the utility and the cost of diminishing the probable error of our knowledge. Its main problem is, how, with a given expenditure of money, time, and energy, to obtain the most valuable addition to our knowledge.

Let r denote the probable error of any result, and write $s = \frac{1}{r}$. Let $\mathrm{U}r \,.\, dr$ denote the infinitesimal utility of any infinitesimal diminution, dr, of r. Let $\mathrm{V}s \,.\, ds$ denote the infinitesimal cost of any infinitesimal increase, ds, of s. The letters U and V are here used as functional symbols. Let subscript letters be attached to r, s, U, and V, to distinguish the different problems into which investigations are made. Then, the total cost of any series of researches will be

$$\Sigma_i \int \mathrm{V}_i\, s_i \,.\, ds_i\,;$$

and their total utility will be

$$\Sigma_i \int \mathrm{U}_i\, r_i \,.\, dr_i\,.$$

The problem will be to make the second expression a maximum by varying the inferior limits of its integrations, on the condition that the first expression remains of constant value.

The functions U and V will be different for different researches. Let us consider their general and usual properties. And, first, as to the relation between the exactitude of knowledge and its utility. The utility of knowledge consists in its capability of being combined with other knowledge so as to enable us to calculate how we should act. If the knowledge is uncertain, we are obliged to do more than is really necessary, in order to cover this uncertainty. And, thus, the utility of any increase of knowledge is measured by the amount of wasted effort it saves us, multiplied by the specific cost of that species of effort. Now, we know, from the theory of errors, that the uncertainty in the calculated amount of effort necessary to be put forth may be represented by an expression of the form

$$c\sqrt{a + r^2}\,,$$

where a and c are constants. And, therefore, the differential coefficient of this, multiplied by the specific cost of the effort in question, say $\frac{h}{c}$, gives

$$\mathrm{U}r = h\frac{r}{\sqrt{a + r^2}}\,.$$

When a is very small compared with r this becomes nearly constant, and in the reverse case it is nearly proportional to r. An analogous proposition must hold for non-quantitative research.

Let us next consider the relation between the exactitude of a result and the cost of attaining it. When we increase our exactitude by multiplying observations, the different observations being independent of one another as to their cost, we know from the theory of errors that $\int \mathrm{V}s \,.\, ds$ is proportional to s^2, and that consequently $\mathrm{V}s$ is proportional to s. If the costs of the different observations are not independent (which usually happens), the cost will not increase so fast relatively to

the accuracy; but if the errors of the observations are not independent (which also usually happens), the cost will increase faster relatively to the accuracy; and these two perturbing influences may be supposed, in the long run, to balance one another. We may, therefore, take $Vs = ks$, where k represents the specific cost of the investigation.

We thus see that when an investigation is commenced, after the initial expenses are once paid, at little cost we improve our knowledge, and improvement then is especially valuable; but as the investigation goes on, additions to our knowledge cost more and more, and, at the same time, are of less and less worth. Thus, when chemistry sprang into being, Dr. Wollaston, with a few test tubes and phials on a tea-tray, was able to make new discoveries of the greatest moment. In our day, a thousand chemists, with the most elaborate appliances, are not able to reach results which are comparable in interest with those early ones. All the sciences exhibit the same phenomenon, and so does the course of life. At first we learn very easily, and the interest of experience is very great; but it becomes harder and harder, and less and less worth while, until we are glad to sleep in death.

Let us now apply the expressions obtained for Ur and Vs to the economic problem of research. The question is, having certain means at our disposal, to which of two studies they should be applied. The general answer is that we should study that problem for which the economic urgency, or the ratio of the utility to the cost

$$\frac{Ur \cdot dr}{Vs \cdot ds} = r^2 \frac{Ur}{Vs} = \frac{h}{k} \frac{r^4}{\sqrt{a + r^2}}$$

is a maximum. When the investigation has been carried to a certain point this fraction will be reduced to the same value which it has for another research, and the two must then be carried on together, until finally, we shall be carrying on, at once, researches into a great number of questions, with such relative energies as to keep the urgency-fraction of equal values for all of them. When new and promising problems arise they should receive our attention to the exclusion of the old ones, until their urgency becomes no greater than that of others. It will be remarked that our ignorance of a question is a consideration which has between three and four times the economic importance of either the specific value of the solution or the specific cost of the investigation in deciding upon its urgency.

In order to solve an economical problem, we may use as variables

$$x = \int Vs \cdot ds,$$

or the total cost of an inquiry, and

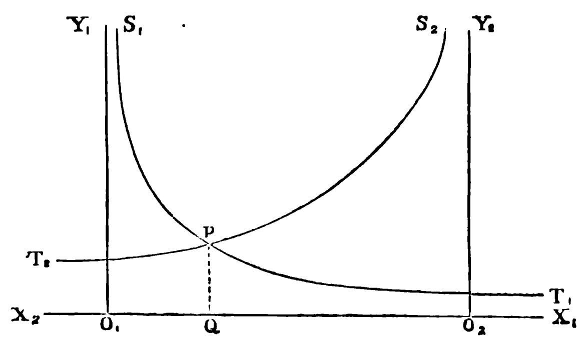
$$y = \frac{Ur \cdot dr}{Vs \cdot ds},$$

or the economic urgency. Then, C being the total amount we have to spend in certain researches, our equations will be

$$C = x_1 + x_2 + x_3 + \text{etc.}$$
$$y_1 = y_2 = y_3 = \text{etc.}$$

Then, expressing each y in terms of x, we shall have as many equations as unknown quantities.

When we have to choose between two researches only, the solution may be represented graphically, as follows:



From any point O_1 taken as an origin, draw the axis of abscissas $O_1\ X_1$, along which x_1, the total cost of the first investigation, is to be measured. Draw also the axis of ordinates $O_1\ Y_1$, along which y_1, the economic urgency of the first investigation, is to be measured. Draw the curve $S_1\ T_1$ to represent the relations of x_1 and y_1. Take, on the axis $O_1 X_1$, a point O_2 such that $O_1\ O_2$ shall measure the total cost of the two investigations. Let x_2, the total cost of the second investigation, be measured on the same axis as x_1, but in the opposite direction. From O_2 draw the axis of ordinates $O_2\ Y_2$ parallel to $O_1\ Y_1$, and measure y_2, the economic urgency of the second investigation, along this axis. Draw the curve $S_2\ T_2$ to represent the relations of x_2 and y_2. Then, the two curves $S_1\ T_1$ and $S_2\ T_2$ will generally cut one another at one point, and only one, between the axes $O_1\ Y_1$ and $O_2\ Y_2$. From this point, say P, draw the ordinate P Q, and the abscissas $O_1\ Q$ and $O_2\ Q$ will measure the amounts which ought to be expended on the two inquiries.

According to the usual values of U and V, we shall have

$$y = \frac{1}{4}\,\frac{h\,k}{x\sqrt{a\,x^2 + \frac{1}{2}k\,x}}\,.$$

In this case, when there are two inquiries, the equation to determine x_1 will be a biquadratic. Two of its roots will be imaginary, one will give a negative value of either x_1 or x_2, and the fourth, which is the significant one, will give positive values of both.

Let us now consider the economic relations of different researches to one another. 1st, as alternative methods of reaching the same result, and 2d, as contributing different premises to the same argument.

Suppose we have two different methods of determining the same quantity. Each of these methods is supposed to have an accidental probable error and a constant probable error, so that the probable errors, as derived from n observations in the two ways, are:

$$r_1 = \sqrt{R_1^2 + \frac{\rho_1^2}{n}} \quad \text{and} \quad r_2 = \sqrt{R_2^2 + \frac{\rho_2^2}{n}}\,.$$

The probable error of their weighted mean is

$$\frac{1}{\sqrt{\frac{1}{r_1^2} + \frac{1}{r_2^2}}}\,,$$

if their constant probable errors are known. The sole utility of any observation of either is to reduce the error of the weighted mean; hence,

$$U\,r_1 = D_{r_1}(r_1^{-2}+r_2^{-2})^{-\frac{1}{2}} = (r_1^{-2}+r_2^{-2})^{-\frac{3}{2}}r_1^{-3}.$$

And as the cost is proportional to the number of observations

$$V\,s_1 = k_1\frac{1}{D_{n_1}\,s_1} = \frac{k_1}{D_{n_1}(R_1^2 + \rho_1^2\,n_1^{-1})^{-\frac{1}{2}}} = \frac{2\,k_1\,r_1^3\,n_1^2}{\rho_1^2}\,.$$

Hence, the urgency is (omitting a factor common to the values for the two methods)

$$r_1^2\,\frac{U\,r_1}{V\,s_1} = \frac{}{k_1\rho_1^2\left(1 + n_1\,\frac{R_1^2}{\rho_1^2}\right)^2}\,.$$

And, as the urgency of the two methods ought to be the same at the conclusion of the work, we should have

$$\sqrt{k_1}\,.\,\rho_1\left(1 + n_1\,\frac{R_1^2}{\rho_1^2}\right) = \sqrt{k_2}\,.\,\rho_2\left(1 + n_2\,\frac{R_2^2}{\rho_2^2}\right),$$

which equation serves to determine the relative values of n_1 and n. We again perceive that the cost is the smallest consideration. The method which has the smallest accidental probable error is

the one which is to be oftenest used in case only a small number of observations are made; but if a large number are taken the method with the larger accidental probable error is to be oftenest used, unless it has so much greater a probable constant error as to countervail this consideration. If one of the two methods has only $\frac{1}{p}$th the accidental probable error of the other, but costs p^2 times as much, the rule should be to make the total cost of the two methods inversely proportional to the squares of their constant errors.

Let us now consider the case in which two quantities x_1 and x_2 are observed, the knowledge of which serves only to determine a certain function of them, y. In this case the probable error of y is

$$\sqrt{D_{x_1}y \cdot r_1^2 + D_{x_2}y \cdot r_2^2},$$

and we shall have

$$Ur_1 = 2r_1 \frac{dy}{dx_1}$$

Vs_1 will have the same value as before; but neglecting now the constant error, we may write

$$Vs_1 = 2k_1 \rho_1 n_1^{\frac{1}{2}}.$$

Then the urgency (with omission of the common factor) is

$$\frac{\rho_1^2}{k_1 n_1^2} \cdot \frac{dy}{dx_1},$$

and, as the two urgencies must be equal, we have

$$\frac{n_1}{n_2} = \frac{\rho_1}{\rho_2} \sqrt{\frac{k_2}{k_1}} \sqrt{\frac{\frac{dy}{dx_1}}{\frac{dy}{dx_2}}}.$$

The following is an example of the practical application of the theory of economy in research: Given a certain amount of time, which is to be expended in swinging a reversible pendulum, how much should be devoted to experiments with the heavy end up, and how much to those with the heavy end down?

Let T_d be the period of oscillation with heavy end down, T_u the same with heavy end up. Let h_d and h_u be the distances of the center of mass from the points of support of the pendulum in the two positions. Then the object of the experiments is to ascertain a quantity proportional to

$$h_d T_d - h_u T_u.$$

Accordingly, if dT_d and dT_u are the probable errors of T_d and T_u, that of the quantity sought will be

$$\sqrt{h_d^2 (dT_d)^2 + h_u^2 (dT_u^2)}.$$

We will suppose that it has been ascertained, by experiment, that the whole duration of the swinging being C, and the excess of the duration of the swinging with heavy end down over that with heavy end up being x, the probable errors of the results are

$$dT_d = \sqrt{a + \left(b + \frac{c}{h_d^2}\right)\frac{1}{C+x}}$$

$$dT_u = \sqrt{a + \left(b + \frac{c}{h_u^2}\right)\frac{1}{C-x}}$$

where a, b, and c are constants. Then, the square of the probable error of the quantity sought will be

$$a(h_d^2 + h_u^2) + (b h_d^2 + c)\frac{1}{C+x} + (b h_u^2 + c)\frac{1}{C-x}.$$

The differential coefficient of this relatively to x is

$$-(b h_d^2 + c)\frac{1}{(C+x)^2} + (b h_u^2 + c)\frac{1}{(C-x)^2}.$$

Putting this equal to zero and solving, we find for the only significant root,

$$\frac{x}{\mathrm{C}} = \frac{b\,(h_d^2 + h_u^2) + 2c}{b\,(h_d^2 - h_u^2)} - \sqrt{\left(\frac{b\,(h_d^2 + h_u^2) + 2c}{b\,(h_d^2 - h_u^2)}\right)^2 - 1}$$

when b vanishes, x reduces to zero, and the pendulum should be swung equally long in the two positions. When c vanishes, as it would if the pendulum experiment were made absolutely free from certain disturbing influences, we have

$$\frac{x}{\mathrm{C}} = \frac{h_d - h_u}{h_d + h_u},$$

so that the duration of an experiment ought to be proportional to the distance of the center of mass from the point of support. This would be effected by beginning and ending the experiments in the two positions with the same amplitudes of oscillation.

It is to be remarked that the theory here given rests on the supposition that the object of the investigation is the ascertainment of truth. When an investigation is made for the purpose of attaining personal distinction, the economics of the problem are entirely different. But that seems to be well enough understood by those engaged in that sort of investigation.

APPENDIX No. 15.

MEASUREMENTS OF GRAVITY AT INITIAL STATIONS IN AMERICA AND EUROPE.

UNITED STATES COAST AND GEODETIC SURVEY,
ALLEGHENY, PA., *December* 13, 1878.

C. P. PATTERSON,
Superintendent United States Coast and Geodetic Survey, Washington, D. C.

DEAR SIR: I present herewith the first part of my report on the measurement of gravity at initial stations of Europe and America. I here describe the methods employed and communicate the main results of the research. The discussion of the amount and nature of the errors, of the comparison of the present results with those deducible from the experiments of other men, and of the resulting figure of the earth, together with some other matters, are postponed for a subsequent report.

The acceleration of gravity is one of those quantities which it is the business of a geodetic survey to measure. So it has always been considered; and it is usage which fixes the meaning of the word "survey" in its geodetical sense. The geodesist is expected to do more than make a map of the country. He not only determines, for instance, the declination of the magnetic needle, which may be laid down on the chart, but also the other magnetic constants which cannot be so laid down. Were he to omit to determine the total force of magnetism, he would be held by all scientific men to have neglected a part of his duty. Now, in the same relation in which this constant stands to magnetical declination and inclination, just so stands the acceleration of gravity to the latitude and longitude; and by as much more as the latitude and longitude are essential to a survey relatively to the direction of magnetism, by so much more is the measurement of gravity indispensable in comparison with that of the magnetic force. The very first duty of the geodesist—paramount even to the drawing of a map—is the study of the figure of the earth; and an operation of surveying in which this problem was left out of view would neither merit nor receive the name of geodetical work. But it was the variation of gravity with the latitude which first proved the earth's ellipticity; and it may very well yet turn out that this method is the best way of determining it. At all events, the study of local variations of vertical attraction will find an application in the measurement of the level surface of the earth by triangulation. It is, also, quite certain that the solution of some high problems of geology must be facilitated by the integrated soundings which the pendulum virtually makes of the earth's interior.

While the absolute amount of the acceleration of gravity is, no doubt, a geodetical constant necessary to be determined, a very precise knowledge of it can, in the present state of science, find no practical nor theoretical application. What is chiefly of importance is the relative gravity at different places and times. This is also a quantity far easier to measure. To determine the acceleration absolutely, we must accurately measure both an interval of time and a length; to determine it relatively, we have only to carry the same rigid piece of metal from place to place and determine the duration of some phenomenon in which gravity is chiefly concerned. Moreover, we can fix in some measure the probable error of relative determinations. Most of the conditions of the experiments other than the amount of gravity itself are alike at the different stations. If they were precisely so, no constant errors could affect the relative result except in the second order of magnitudes. Now the accidental errors of observations, the only ones which would remain, can readily be determined by the method of least squares. It is not quite true that no conditions other than gravity vary from station to station. The temperature, for example, varies; and in such a manner that an erroneous coefficient of expansion will produce errors in the relative gravity of stations near the poles and near the equator in a constant direction and similar amount; and so will slightly affect the deduced compression of the earth. So an error in the coefficient of atmospheric effect will produce a constantly similar error in the relative gravity of an elevated and a depressed station, and may thus lead to an extremely erroneous value of the absolute modulus of gravitation and of the mean density

of the earth. There are, also, various conditions relating to the installation of the instruments which are different at different stations, and which give rise to errors which least squares will fail to detect. Such errors are, however, slight in comparison with those which may affect absolute determinations of gravity, into which the constant errors enter to their full amount. A source of error affecting all modern determinations was lately pointed out by the writer of this paper, which had produced errors in the accepted results amounting to one four or five thousandth part of the quantity measured, and in some cases even to more.

The value of gravity-determinations depends upon their being bound together, each with all the others which have been made anywhere upon the earth. In considering how the necessary connections should be made for our work, it seemed to you, sir, and to Prof. Benjamin Peirce, the consulting geometer, as it did to the writer, that to trust to absolute determinations and to the transportation of meters would be more than hazardous, notwithstanding that such had been the recent practice in continental Europe. Your instructions were accordingly issued for the oscillation of the same pendulum at those fundamental stations of Europe where the chief absolute determinations had been made and whence pendulum-expeditions had set out, and at a station in America which would become the initial one for this continent. Similar action followed on the part of the European surveys; for at the meeting of the International Geodetic Congress in Paris, in 1875, it was resolved, at the suggestion of the writer, that the different states should carry their pendulums to Berlin and swing them in the Eichungsamt there. This has already been done by Switzerland and Austria, and will be done hereafter by every survey which is not willing to sacrifice the solution of a great problem to forms of action based on national exclusiveness. Geodesy is the one science the successful prosecution of which absolutely depends upon international solidarity.

STATIONS.

The stations occupied were as follows:

1. *Geneva.*—The pendulum was swung in the observatory, nearly in the same spot, and on the same wooden stand (see illustration No. 26) used for the purpose by Professor Plantamour, whose advice in regard to the conduct of the experiments was invaluable. His pendulum was set up at the east end and ours at the west end of the main hall. The floor of this hall is (as I remember it) not a meter above the level of the ground which, according to Dufour's map, is 407 meters above the level of the sea. The experiments here were made in August and September, 1875. The station must be pronounced unfavorable for accurate pendulum-work, both from its exposure to changes of temperature and from the slight stability of the asphalt floor and of the tripod.

After the experiments at Geneva the pendulum was injudiciously intrusted to a company in Plainpalais, of whom a vacuum chamber had been ordered. It suffered grave injury in consequence, and was repaired by MM. Brunner, in Paris. In this way the operations at Geneva are completely separated from those at the other stations, and are deprived of much of their value.

2. *Paris.*—M. Wallon, minister of worship and public instruction, authorized pendulum-experiments at the Observatory of Paris. The observations were made in the Hall of the Meridian, in the alcove at the north end. The center of the pendulum-stand was 89 cm. east of the meridian-mark, and opposite the reading 2738 cm. on the meridian-mark. The pendulum-stand stood directly on the floor, and the center of gyration of the pendulum was 29 cm. above the floor. A pendulum-stand, believed to be that of Biot, is by measurement 735 cm. east of the meridian, and opposite 450 cm. on the meridian-mark. Its fulcrum is 171 cm. above the floor. On this subject, M. C. Wolf, astronomer at the observatory, to whose politeness throughout the occupation of the station the writer is much indebted, kindly communicates the following details:

"Borda a opéré dans une salle et contre un mur qui n'existent plus; la hauteur du sol de cette salle au-dessus du niveau de la mer est 67 mètres. L'annuaire du bureau des longitudes donne 65 mètres.

"J'ai pris sur un ancien plan de l'observatoire la position du mur de Borda: son centre était à 14.72 toises (28.69 mètres) de la ligne de la méridienne, à l'est, et au sud à $9^t.89$ ($19^m.28$) du puits de l'observatoire, dont l'axe est sur la méridienne.

"Les coordonées de la station de Biot par rapport à la même ligne et au même puits sont:

Distance à la méridienne....................................	$7^m.34$ est
" au puits suivant la méridienne....................	$10^m.23$ sud

"Vous étiez placé vous-même presque sur la méridienne, à moins d'un mètre à l'est, et à $12^{m}.70$ du puits vers le nord.

"La hauteur des deux dernières stations [no doubt the floor is meant] au-dessus de celle de Borda est $7^{m}.05$, par conséquent $74^{m}.05$ au-dessus du niveau de la mer."

The level of the ground in the middle of the south face of the observatory above that of the sea is, according to the general staff, 58.8 meters. M. Biot gives as the elevation of his station above the sea 70.25 meters. He erroneously states that Borda's was at the same level. De Freycinet gives 72.28 meters as the altitude of his station. Our experiments at Paris were made during the months of January and February, 1876.

The station at Paris was favorable in regard to the uniformity of temperature, but unfavorable from the excessive instability of the floor.

3. *Berlin.*—The pendulum was swung in Berlin in the large comparison-room of the Imperial Eichungsamt in the garden of the observatory. Plans of this building have been promised by the director, Professor Förster, for this report; but as they have not yet arrived the precise point occupied will be stated in an appendix. The station was very near that of Bessel, but about three meters higher. The experiments were made from April 15 to June 12, 1876. This station was favorable in regard to stillness and stability, but unfavorable owing to changes of temperature. The writer here enjoyed the inestimable advantage of the counsel of the Nestor of geodesy, Genera Baeyer, and also that of great interest in the experiments and attention to everything which could affect the success of them on the part of Professor Förster.

4. *Kew.*—In England, the pendulum was swung at the Kew Observatory in the old deer-park at Richmond, Surrey. The observatory is a meteorological station kept up by a committee of the Royal Society, but is apparently as fundamental a station as there is available in England. The ground is 24 feet above the level of the sea and our pendulum was nearly at the level of the ground. The experiments were made in July, 1876. It proved an excellent place both for steadiness of temperature and for stability Fortunately, the director of the observatory, Mr. Whipple, thoroughly understands the art of oscillating the pendulum, and was most obliging in furthering the investigation in many ways.

5. *Hoboken.*—The pendulum was swung in a dark chamber in the cellar of the Stevens Institute of Technology. Notwithstanding the kindness of the authorities of the institute in permitting and facilitating the experiments in various ways, and the advantage of the counsels of the eminent physicists resident there, especially those of my friend Professor A. M. Mayer, this station is objectionable from its being situated in a private institution. Otherwise, however, it is a suitable place, except that it is impossible to measure the length of the pendulum there with any accuracy owing to effects of temperature. The latitude of the station is 40° 44′.5, the longitude is 74° 02′ west, and the height above the mean sea-level is about 10 meters. The position in reference to the harbor of New York is shown in the illustration No. 26*a*.

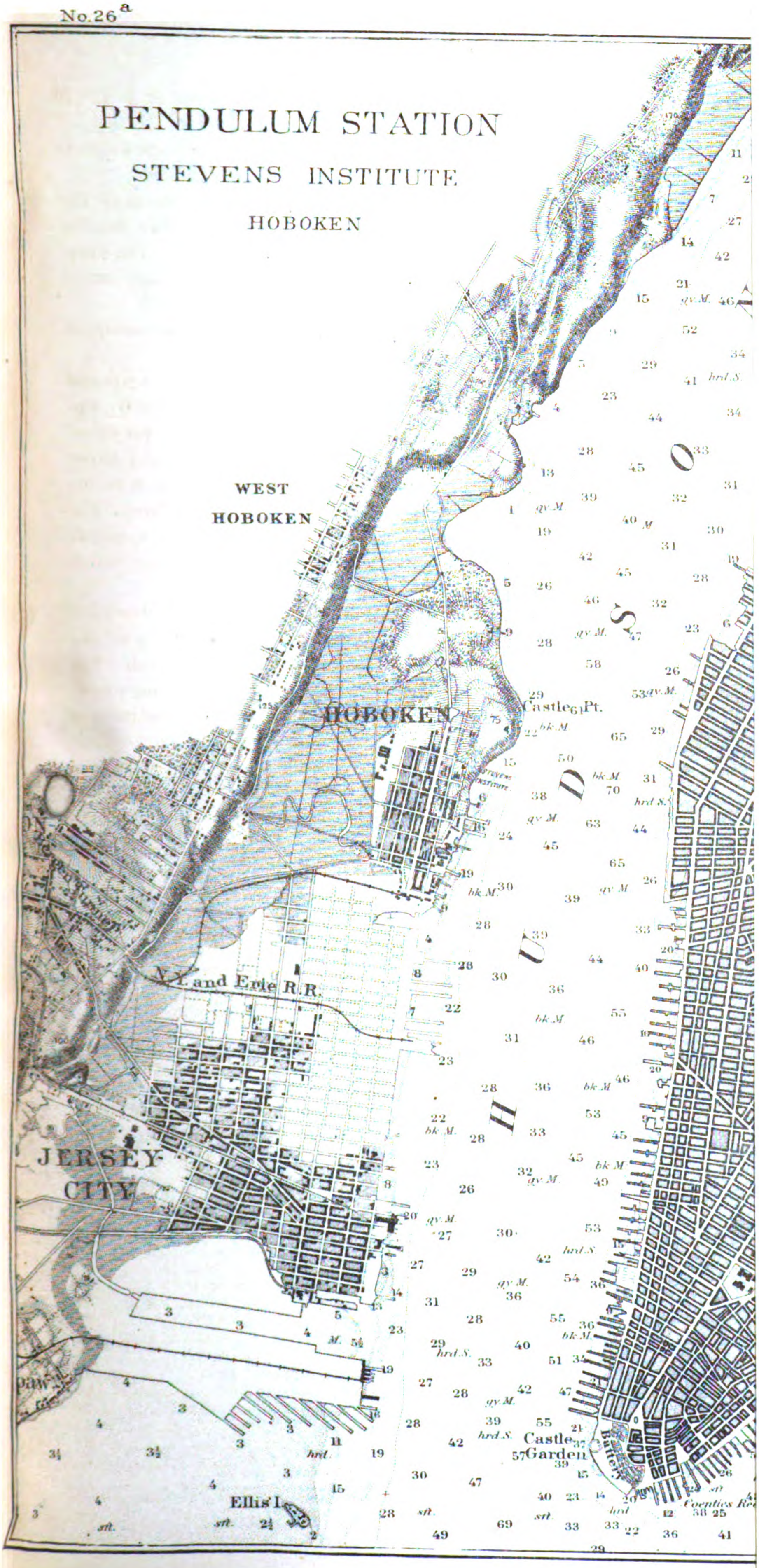
INSTRUMENTS.

The chief instrument was a Bessel reversible pendulum of one meter length between the knife-edges, admirably constructed by Messrs. Repsold, and nearly an exact copy of the Prussian instrument described by Bruhns in his account of Dr. Albrecht's experiments. One-half this pendulum is shown in illustration No. 27. Its mass is 6308 grams. The dimensions of its principal parts are as follows:

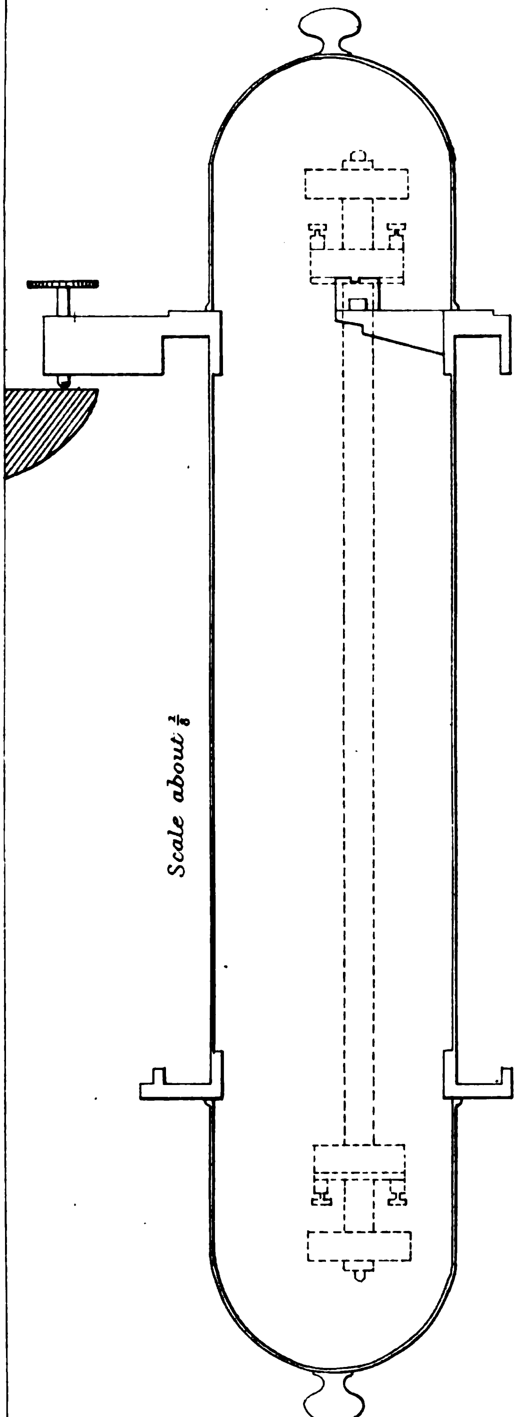
	Centimeter.
Height of cone at end	0.5
Length of little cylinder	1.2
Diameter of little cylinder	1.0
Diameter of collar outside bob	4.9
Height of collar	0.9
Diameter of bob, heavy	11.48
Diameter of bob, light	11.42
Height of bob, heavy	3.25
Height of bob, light	3.18
Diameter of collar below bob	4.78
Height of collar below bob	2.4
Diameter of stem	4.33
Distance (nearest) bob to bob	115.25
Length of knife	9.55

	Centimeter.
Height of knife	1.8
Thickness of knife	1.4
Height from bottom of brass oblong to top of knife	3.4
Thickness of brass piece	1.32
Height of tops of thumb-screws above top of knife	2.05
Breadth of brass for screws	2.35
Length of upper projection on stem below knife	1.4
Diameter of upper projection on stem below knife	5.0
Length of lower projection on stem below knife	1.4
Diameter of lower projection on stem below knife	5.0
Length of hole for tongue	7.5
Breadth	2.6
Thickness of metal	0.18

No. 26[a]

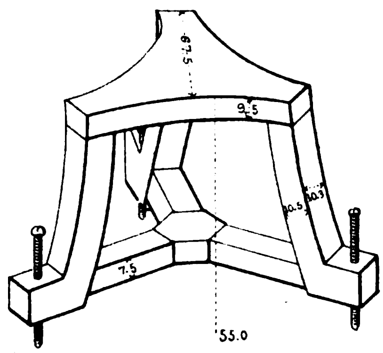

PENDULUM STATION
STEVENS INSTITUTE
HOBOKEN
WEST HOBOKEN
HOBOKEN
Castle Pt.
HUDSON
N.Y.L. and Erie R.R.
JERSEY CITY
Castle Garden
Ellis I.

No. 28



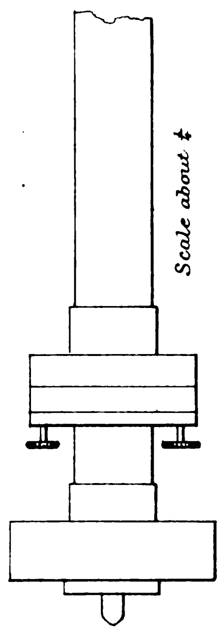
Geneva Pendulum Support.

No. 26



Geneva wooden stand
(measures in centimeters.)

No. 27



Bessel Reversible Pendulum.

In using the vertical comparator which forms a part of the instrument, the intention of the makers seems to have been that the pendulum-meter should be set vertical by means of a spirit-level on a brass straddle provided for the purpose. Instead of this, a plumb-line has been used. This is so made as to be capable of movement in any horizontal direction. The point of support can also be raised or lowered and the whole can be rotated on a vertical axis. In this way, glass scales may be observed, which form part of the plumb; and any error in their verticality is eliminated by reversal. The instrument is first approximately adjusted; the axis of rotation of the comparator is made accurately vertical and the upper microscope is focused on the knife-edge. Then the vertical wire of the lower microscope is made to bisect the plumb-line and the upper microscope is turned about the vertical axis until it also bisects the same vertical line. Afterward, the plumb-line having been brought into the focus of the upper microscope, the lower one is advanced or retracted until it is in focus on the plumb-line below. The microscopes having been so adjusted the meter is adjusted by means of them.

A separate pendulum-support, with a vacuum chamber, constructed under my direction by the Plainpalais company, and called the Geneva support, was used at Hoboken. A vertical section of this support (suppressing various details) is shown on illustration No. 28. The supporting part consists essentially of a solid brass ring with three projections for screw-feet and a tongue to receive the knife-edge cast in one piece. The vacuum chamber is a metallic cylinder covered with bell-glasses at the two ends.* Each screw-foot is furnished with two powerful binding-screws. Only that part of the tongue below the level of the upper surface of the brass ring is a part of the same casting. The upper part is fixed by screws. The instrument is provided with apparatus for raising the pendulum off the knife-edges and letting it down again, another for setting it in motion, supports for thermometers, graduated arc, &c. The graduated arc is divided into thousandths of the radius. Messrs. Stackpole and Brothers, of New York, have made this troublesome graduation with extreme accuracy, upon the arc now in use, and have generously presented it to the survey.

Various other instruments were used which will be described in giving an account of the observations made with them.

OBSERVATIONS OF THE DURATION OF AN OSCILLATION.

The duration of oscillation was ascertained by chronographing 100 transits of the point of the pendulum over the vertical wire of a reading-telescope. Equal numbers of transits were taken from right to left and from left to right, so that any effect from the wire not being at the equilibrium-point was eliminated. At least two seconds elapsed between successive records. The time-keeper was generally a chronometer breaking every two seconds. The chronometer-breaks and signals of pendulum-transits were recorded by the same pen, and interferences were avoided by choosing among the following four methods:

A. 25 transits to the right; 50 to the left; 25 to the right.
B. 50 transits to the left; 50 to the right.
C. 25 transits to the left; 50 to the right; 25 to the left.
D. 50 transits to the right; 50 to the left.

The chronograph is a fillet instrument regulated by a reed and constructed by Breguet. It has three pens. The fillets have been measured to tenths of seconds and the hundredths have been estimated, except in the second readings of the Berlin fillets, where the hundredths were measured with a scale devised and constructed for the purpose.

Observations of the transits were taken when the pendulum reached an arc of oscillation of 2°, 1½°, 1°, and ½°, on each side of the vertical. The object of the intermediate transits at 1½° and 1° will be seen in the second part of the report, which treats of the errors of the results. By taking the transits at fixed arcs, the condition that the pendulum should be equally affected by the air with heavy end up and heavy end down was secured with certainty. It has been objected that this

* The leakage of the chamber increased the pressure by about that of a tenth of a millimeter of mercury per hour.

plan makes the experiment with heavy end up of too short duration. To remedy this, at Kew the pendulum was swung with heavy end up both before and after every experiment with heavy end down, so that there were twice as many experiments with heavy end up as with heavy end down. The question of the proper arrangement of the experiments in this respect belongs to the theory of the Economy of Research, which is treated in Appendix No. 14.

In order to avoid any possible difference of personal equation in noting the transits when the pendulum was moving rapidly at the beginning and slowly at the end of the experiments, different powers were employed upon the reading-telescope, so that the apparent velocity was about the same at the last as at the first set of transits.

CORRECTIONS.

The observed duration has to receive the following corrections:

1. The correction for the rate of the time-keeper;
2. The correction for amplitude of oscillation;
3. The correction for pressure and temperature of the air;
4. The correction for the expansion of the metal by heat;
5. The correction for the slip of the knives;
6. The correction for the wear of knives;
7. The correction for inequality of knives;
8. The correction for stretching of pendulum by weight of heavy bob when the latter is down;
9. The correction for the flexure of the support;
10. The correction for attractions of sun, moon, and tide;
11. The correction for elevation above sea level.

ON THE CORRECTION FOR THE RATE OF THE TIME-KEEPER.

The stations at Geneva, Paris, and Berlin, being astronomical observatories, the rates of their clocks were determined by the astronomers there.

At Geneva, the transits of the pendulum were registered on a fillet-chronograph which was found there, together with the even seconds of break-circuit chronometer Hutton 202. The second-hand of the sidereal clock was, before and after the experiments of each day, observed through a telescope, and its seconds registered in the same way. The following table, showing the corrections of the clock for 20^h sidereal time of every day on which stars were observed, was kindly communicated by Professor Plantamour:

Date.	Correction, Geneva clock.	Rate.
1875.	*s.*	*s.*
Aug. 27	+ 56.39	
		+ 0.49
31	+ 58.36	
		+ 0.57
Sept. 1	+ 58.93	
		+ 0.60
2	+ 59.53	
		+ 0.65
3	+ 60.18	
		+ 0.63
4	+ 60.81	
		+ 0.70
5	+ 61.51	
		+ 0.62
6	+ 62.13	
		+ 0.68
7	+ 62.81	
		+ 0.78
8	+ 63.59	
		+ 0.67
11	+ 65.60	
		+ 0.71
12	+ 66.31	
		+ 0.45
13	+ 66.76	
		+ 0.60
14	+ 67.36	
		+ 0.70
16	+ 68.77	
		+ 0.56
17	+ 69.33	
		+ 0.76
18	+ 70.09	

These rates have been adopted in the calculations.

The comparisons between the chronometer and clock, and the rate of the chronometer as deduced from them for each day's observations, will appear in their proper place in the full account of the pendulum-work in my next report.

At Paris the pendulum-transits were chronographed together with the beats of the meridian clock. The corrections and rates of this clock were supplied by the observatory in two lists, which are here appended. In transmitting the second, M. Wolf makes the following remarks:

"J'ai examiné avec attention la marche diurne de la pendule sur laquelle vous avez observé et compté la seconde. Sa marche diurne normale, résultant d'un très-grand nombre d'observations faites à différentes époques de l'année, varie de $+0^s.05$ à $+0^s.07$. C'est en effet ce que nous retrouvons pour le mois de février, comme il résulte du tableau ci-dessous. Mais en janvier, il est évident qu'il s'est produit une perturbation dont je ne puis deviner la cause. Quoiqu'il en soit, il me paraît nécessaire d'admettre pour la marche diurne

$+0^s.20$ du 24 janvier au 2 février
$+0$:07 du 2 février au 24.

"Voici en effet le tableau des corrections observées en regard desquelles je place les corrections calculées avec les marches précédentes: [Here M. Wolf inserts the second list given below.] Ces corrections se rapportent toutes à 9^h temps moyen à $\frac{1}{4}$ d'heure près.

"La seule différence trop forte est celle du 4 février; la correction de ce jour a été obtenue par un observateur différent de celui qui a déterminé toutes les autres.

"Quelle que soit d'ailleurs la marche que vous admettiez, il me semble que l'erreur qui peut en résulter sur la durée de la seconde sidérale, c'est toujours de beaucoup inférieure à celle qui résulte de la mesure des oscillations de votre pendule."

Corrections of the Paris meridian-clock.

FIRST LIST.

Date.	Temps sidéral.	Lunette de Gambey. M. Léon.	Cercle méridien. M. Périgord.	Cercle méridien. M. Folain.
1876.	h. m.	s.		
Jan. 5	3 3	+12.02		
10	3 40	+12.46		
15	7 0	+13.37		
24	4 40	+15.09	+15.35	
25	7 30	+15.19	+15.60	
26			+15.85	
27	4 25	+15.83		
28	5 40	+15.88	+16.22	
29	5 0	+15.91	+16.35	
31	6 3	+16.41	+16.75	
Fév. 1			+17.03	
4				+17.59
7			+18.50	
9			+18.50	
10				+18.75
11			+18.75	
12			+18.82	
14			+18.46:	
15			+19.28	

SECOND LIST.

Date.	Obs.	Calc.
1876.	s.	
Jan. 24	+15.35	+15.40
25	+15.60	+15.60
26	+15.85	+15.80
28	+16.22	+16.20
29	+16.35	+16.40
31	+16.75	+16.80
Fév. 1	+17.05	+17.00
2	+17.32	+17.19
4	+17.62	+17.33
7	+17.53	+17.54
9	+17.57	+17.68
10	+17.72	+17.75
11	+17.76	+17.82
12	+17.87	+17.89
22	+18.50	+18.59
23	+18.64	+18.66

I cannot presume to review the judgment of the Paris Observatory upon the errors of its own observers, and the rates given in the last column are therefore adopted. Illustration No. 29 exhibits the concordance of the observations with these rates.

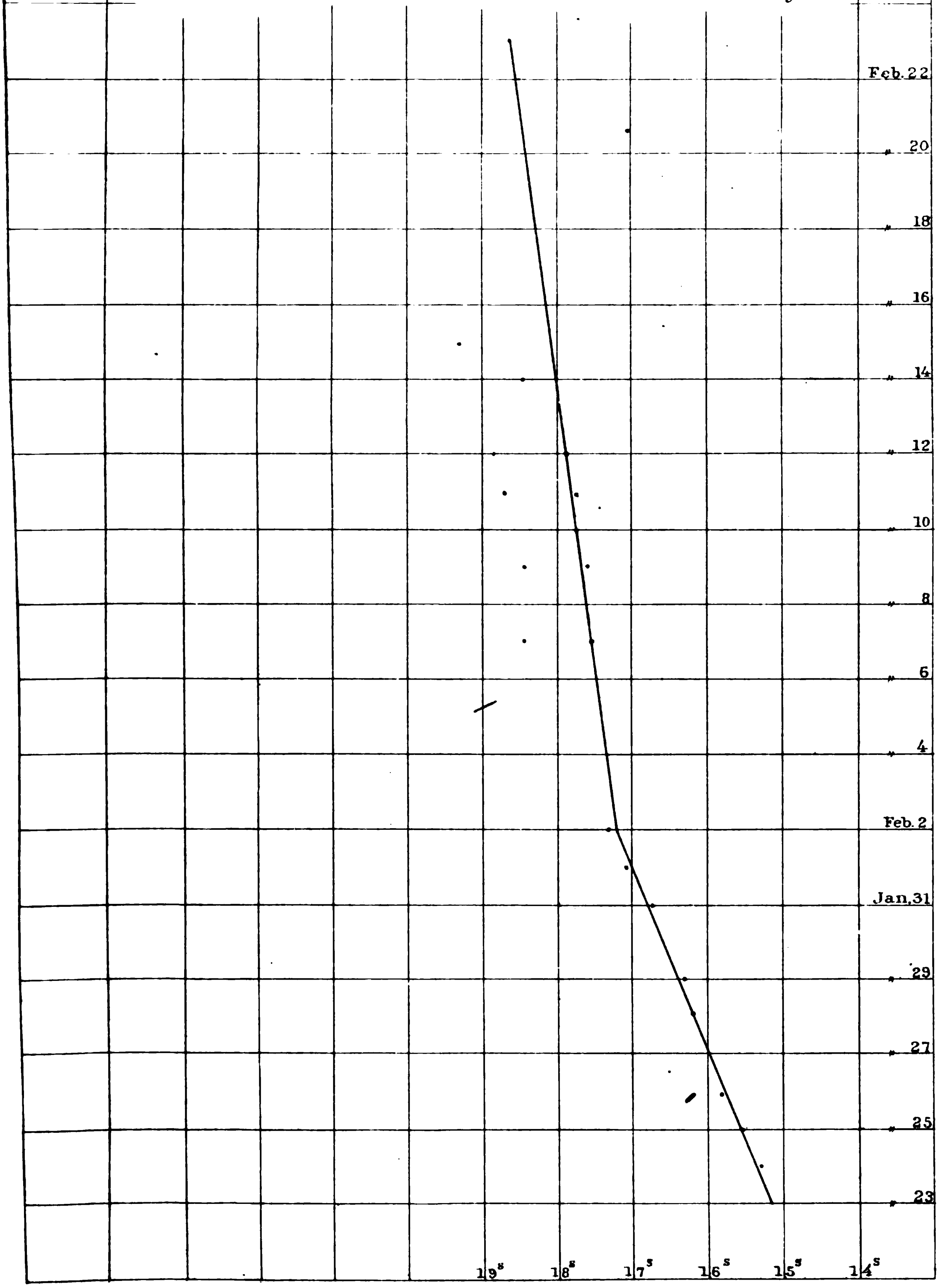
At Berlin the clock, whose seconds were chronographed with the signals of pendulum-transits, was a subsidiary one in the observatory, designated as Serffert. Every day, before and after the experiments, it was put on to one of the observatory chronographs with the clock of the observatory. The corrections were communicated in the following list:

Stand und Gang von Serffert, 1876, April 15–Juni 16.

1876.	T_3-S	$\Delta h.\ T_3$	$\Delta h.\ S$	Tägl. G. S.
	s.	s.		
April 15.63	26.29			
16.13	26.58			
.63	26.87			
17.13	27.14	− 0.17	+26.97	
.63	27.33			
18.13	27.48			− 0.23
.63	27.61			
19.13	27.75	− 1.25	+26.50	
.63	27.81			
20.13	27.89			− 0.17
.63	27.95			
21.13	28.03			
.63	28.06	− 1.98	+26.08	
22.13	28.14			
.63	28.24			
23.13				
.63	28.39			− 0.03
24.13				
.63	28.66			
25.13	28.90			
.63	29.00			
26.13	29.33	− 3.37	+25.96	
.63	29.52			+ 0.04
27.13	29.73	− 3.73	+26.00	
.63	29.90			
28.13	30.05			
.63	30.16			− 0.19
29.13	30.29			
.63	30.44			
30.13	30.61			
.63	30.69	− 5.36	+25.33	
Mai 1.13	30.81			− 0.16
.63				
2.13	31.03	− 5.94	+25.09	
.63				
3.13	31.30			+ 0.02
.63	31.53			
4.13	31.82	− 6.69	+25.13	
.63	32.15			

No. 29

Rates of the Meridian Clock of the Paris Observatory



Stand und Gang von Serffert, 1876, *April* 15–*Juni* 16—Continued.

1876.		T_3-S	$\Delta h.\ T_3$	$\Delta h.\ S$	Tägl. G. S.
		s.	s.		
Mai	5.13	32.41			
	.63	32.64			
	6.13	32.92			+ 0.16
	.63	33.15			
	7.13	33.31			
	.63	33.46	− 7.77	+25.69	(1)
	8.13	33.71			
	.63	33.98			
	9.13	34.28			+ 0.28
	.63	34.57			
	10.13	34.88			
	.63	35.15	− 8.62	+26.53	
	11.13	35.49			
	.63	35.78			+ 0.35
	12.13	36.06	− 9.00	+27.06	
	.63				(2)
	13.13	36.59			
	.63	36.89			
	14.13	37.19			+ 0.11
	.63	37.41			
	15.13	37.70			
	.63	37.98	−10.54	+27.44	
	16.13	38.34			
	.63	38.65			
	17.13	38.96			
	.63	Es wurde eine kleine Verbesserung der Kompensation ausgeführt.			
	18.13				
	.63				
	19.13				
	.63				
	20.13	10.58	−12.26	− 1.68	
	.63	10.45			
	21.13	10.38			− 0.39
	.63	10.24	−12.50	− 2.26	
	22.13	10.08			
	.63	9.88			− 0.53
	23.13	9.69	−12.74	− 3.05	
	.63				
	24.13	9.32			− 0.65
	.63	9.13	−13.15	− 4.02	
	25.13	8.96			
	.63	8.81			− 0.64

Anm. 1). Quecksilbertropfen höher gestellt.

Anm. 2). Die Untersuchung der Gänge 1876, Febr. 25, bis Mai 15, ergiebt

$$\frac{d\,(\text{Täglich. Gang})}{d\ \text{Barom.}} = +\,0^{s}.018 \text{ für } +1^{mm}.$$

Stand und Gang von Serffert, 1876, *April* 15–*Juni* 16—Continued.

1876.		T_3-S	$\Delta h.\ T_3$	$\Delta h.\ S$	Tägl. G. S.
		s.	s.	s.	
Mai	26.13	8.69			
	.63	8.54	−13.85	− 5.31	
	27.13	8.40			
	.63	8.27			
	28.13	8.12			− 0.60
	.63	8.03			
	29.13	7.92			
	.63	7.80	−14.91	− 7.11	
	30.13	7.76			
	.63	7.70			
	31.13	7.65			
	.63	7.54			
Juni	1.13				− 0.44
	.63	7.35			
	2.13	7.24			
	.63	7.06			
	3.13	6.94			
	.63	6.72	−16.01	− 9.29	
	4.13	6.49			
	.63	6.31			− 0.50
	5.13	6.16			
	.63	5.96	−16.25	−10.29	
	6.13	5.74			
	.63	5.46			− 0.49
	7.13	5.22			
	.63	4.96	−16.24	−11.28	
	8.13	4.81			
	.63				
	9.13	4.42			
	.63	4.23			− 0.42
	10.13	4.08			
	.63	3.95			
	11.13	3.85			
	.63	3.70	−16.66	−12.96	
	12.13	3.52			
	.63	3.35			
	13.13	3.23			
	.63	2.98			
	14.13	2.78			− 0.50
	.63	2.56			
	15.13	2.36			
	.63	2.17			
	16.13	1.97	−17.19	−15.22	
	.63	1.80			

An independent set of comparisons between Serffert and the normal clock of the observatory is given below, the differences between it and the previous table being usually very slight. In the table below the column headed O gives $T_3 - S$ as directly observed, and I as interpolated from the table just given:

Date.	T_3-S, O	T_3-S, I	O—I
1876.	s.	s.	s.
April 19.94	27.88	27.86	+ .02
21.01	28.01	28.01	.00
23.91	28.45	28.47	— .02
24.12	28.50	28.52	— .02
24.89	28.77	28.78	— .01
25.12	28.89	28.90	— .01
25.89	29.22	29.21	+ .01
26.11	29.31	29.32	— .01
27.90	30.00	29.98	+ .02
28.12	30.06	30.05	+ .01
28.88	30.15	30.22:	— .07
29.12	30.30	30.29	+ .01
29.89	30.57	30.53:	+ .04
30.12	30.62	30.61	+ .01
May 1.90	31.03	30.98:	+ .05
2.12	31.03	31.03	.00
2.89	31.25	31.24	+ .01
3.92	31.83	31.70:	+ .13
4.11	31.81	31.81	.00
4.89	32.29	32.29	.00

There are but four cases of discordance, all occurring where the comparison of this set was taken midway between two of the former set.

On comparing the daily rates of the two clocks designated as T_3 and S, during the time of the pendulum-observations, it will be found that the latter went as well as the former, as shown in the following table:

Date.	Daily rate, T_3	Daily rate, S	Diff. from mean T_3	Diff. from mean S
1876.	s.	s.	s.	s.
Apr. 19–21	— .49	— .17	— .12	— .07
21–26	— .31	— .03	+ .06	+ .07
26–27	— .36	+ .04	+ .01	+ .14
27–30	— .47	— .19	— .10	— .05
May 0– 2	— .23	— .16	+ .14	— .06
2– 4	— .38	+ .02	— .01	+ .12

For the observations at Kew, the time was kept by the four chronometers—

Hutton 202, sidereal;
Dent 2171, mean solar;
Frodsham 3525, mean solar;
Frodsham 3474, mean solar.

The solar chronometers were all compared with No. 202, by coincidence of beats, at least once a day, from June 30 to July 12, inclusive, but the comparison of June 30 was rejected because the

chronometers had not then been in place long enough to acquire uniform rates. The following table gives the results of these comparisons, the excess of each chronometer over No. 3525 being taken.

Kew.—Comparison of chronometers [2171, 3525, *and* 3474 *are reduced to sidereal time*].

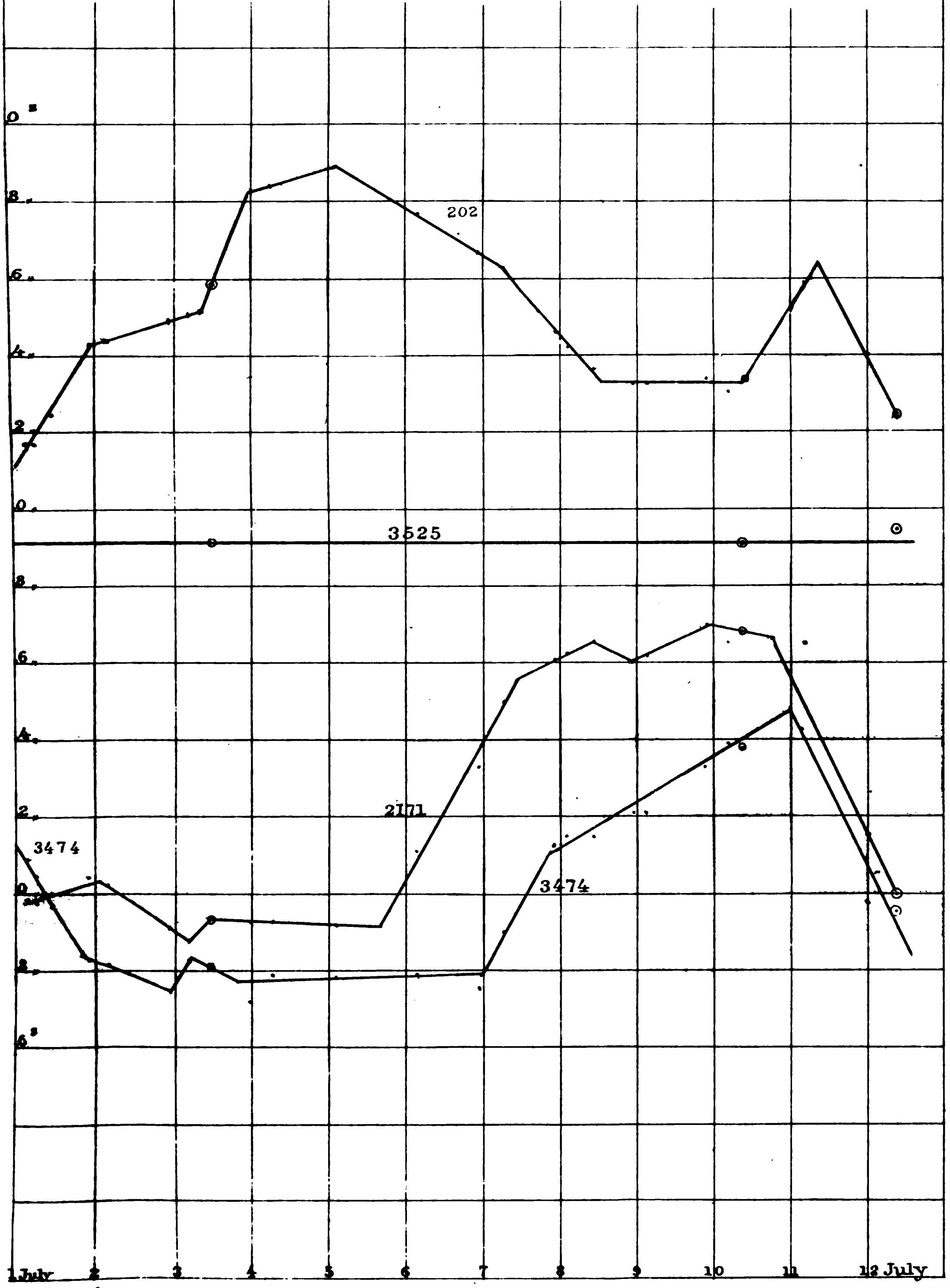
	Excess over Frodsham 3525 of—		
	Hutton 202.	Dent 2171.	Frodsham 3474.
1876.	*m. s.*	*m. s.*	*m. s.*
June 30.13	+ 3 8.61	+ 0 1.30	+ 0 20.87
July 1.12	2 57.94	0.14	19.79
1.26	56.43	+ 0.02	19.71
1.47	54.15	— 0.12	19.57
1.92	49.42	0.43	19.31
2.10	47.49	0.57	19.25
2.94	38.42	1.34	18.96
3.16	35.99	1.53	18.97
3.47	32.73	1.70	18.88
3.98	27.40	2.10	18.65
4.25	24.47	2.31	18.65
5.09	15.30	2.96	18.41
6.15	3.60	3.58	18.13
6.92	1 55.17	3.94	17.90
7.25	51.44	4.03	17.94
7.91	44.10	4.42	17.99
8.12	41.77	4.56	17.97
8.45	38.16	4.79	17.88
8.95	32.63	5.22	17.80
9.12	30.79	5.33	17.76
9.91	22.19	5.85	17.67
10.18	19.17	6.11	17.65
10.39	16.87	6.22	17.59
11.11	9.16	6.93	17.43
11.99	0 59.47	7.98	16.73
12.37	+ 0 55.21	— 0 8.43	+ 0 16.63

In the transit-observations, a Dollond transit belonging to the observatory, was used. These observations were taken under very great disadvantages. The transit-room, which was not in the observatory building, but located just outside the east wall, was not large enough to allow a place for the chronograph, so that the observer (Mr. H. Farquhar) was obliged frequently to leave this room in order to see to the recording of his signals. The instrument was one of small magnifying power, with a long interval between the wires (about 26^s at the equator), so that a special journey had to be made during the passage of the high northern stars, to wind up the chronograph and see that the pens were working. It was, moreover, in not very good condition, nor very steady. For these reasons, though many stars were observed every fair evening, great difficulty was found in getting a satisfactory correction from them. In illustration No. 30, which shows the correction to each of the chronometers after applying a uniform rate, the comparisons made at the time of the transit-observations are distinguished by circles, and only the observations of the 3rd, 10th, and 12th are taken, it having been found impossible to bring the separate stars, in the observations of the 1st and the 8th, into concordance.

Chronometer 3525 has been considered as having one uniform rate of + $0^s.23$ per day, from the beginning to the end of the pendulum-experiments.

No. 30.

U.S. Coast Survey. Pendulum at Kew. Correction to Chronometers after applying uniform rates. (Star observations of the 1st and 8th rejected.)



This supposition gives as the rate of No. 202, the chronometer used, during each day when the pendulum was swung—

1876.	Daily rate of 202.
	s.
July 1	+ 10.99
2	11.10
3	11.05
4	11.01
7	11.24
8	11.35
9	11.15
10	11.26

These rates have been adopted in the calculation.

At Hoboken the time was observed with the United States Coast Survey portable transit No. 5, by Simms. It was kept by break-circuit chronometers—

Hutton	202	(sid. time),
Bond	380	(sid. time),
Negus	1589	(sid. time),
Negus	1591	(mean time),

and a part of the time by

Bond	387	(sid. time).

For the observations of April and May, 1877, which were intended to show the difference in the time of oscillation on a stiff and on a flexible stand, and for the regular swings of June, 1877, the time-observations were commenced by Subassistant Edwin Smith on March 24, and were continued until June 29, inclusive. The chronometer used in the observations of time was usually Negus 1589. The following table shows the residuals of the time-observations. The reduction was made by field-methods, by Subassistant Smith:

			March.		April.							May.			
	P. D.	Z. D.	1	24	6	11	12	17	23	24	25	2	3	7	12
	°	°													
δ Geminorum	68	+19	+.04 W.	..	..	..	..	..	..	..	..	..	..	..	..
P. VII, 67	21	−28	+.01 W.	..	..	..	..	..	..	..	..	..	..	..	..
α Geminorum	58	+ 9	+.20 W.	..	..	..	rej.	..	..	..	..	..	..	..	..
α Canis Minoris	84	+35	−.28 W.	..	..	..	−.03 E.	..	..	..	..	..	..	..	..
β Geminorum	62	+12	+.02 E.	..	..	..	+.14 E.	..	..	..	..	..	..	..	..
3 H Ursæ Majoris	21	−28	+.02 E.	..	..	..	..	..	..	..	..	..	..	..	..
κ Cephei (L. C.)	−13	−62	..	..	..	..	−.10 W.	..	..	..	..	..	..	..	..
ε Hydræ	83	+34	..	..	..	+.04 W.	+.08 W.	−.10 W.	..	..	..	..	..	..	..
ι Ursæ Majoris	41	− 8	..	+.09 W.	..	.00 W.	−.09 W.	+.02 W.	..	..	..	..	..	..	..
κ Cancri	79	+30	..	..	−.03 E.	−.04 W.	..	+.04 W.	..	..	..	..	..	..	..
1 H Draconis	8	−41	..	−.09 W.	+.03 E.	..	..	..	−.15 E.	−.24 W.	−.04 E.	..	..	..	..
α Hydræ	98	+49	..	..	..	..	..	+.07 E.	−.16 E.	+.01 W.	−.08 E.	+.07 W.	..	..	..
d Ursæ Majoris	20	−30	..	..	−.05 W.	..	..	.00 E.	+.15 E.	+.25 W.	−.02 E.	..	..	..	..
θ Ursæ Majoris	38	−11	..	+.01 W.	..	..	..	.00 E.	+.10 E.	..	+.02 E.	+.06 W.	..	..	..
ε Leonis	66	+16	..	−.05 E.	−.04 W.	..	..	..	+.01 W.	−.03 E.	+.07 W.	−.13 W.	−.03 E.	..	..
μ Leonis	63	+14	..	+.02 E.	+.07 W.	..	..	..	+.02 W.	+.03 E.	+.06 W.	+.05 E.	+.04 E.	..	..
α Leonis	77	+28	..	..	..	..	..	..	..	..	..	+.04 E.	+.02 W.	..	+.03 E.
32 Ursæ Majoris	24	−25	..	..	..	..	..	..	..	..	..	−.08 E.	.00 W.	..	..
γ_1 Leonis	70	+20	..	..	..	..	..	..	..	..	..	..	−.02 W.	+.03 W.	−.03 E.
9 H Draconis	14	−36	..	..	..	..	..	..	..	..	..	..	..	−.01 W.	..
ρ Leonis	80	+31	..	..	..	..	..	..	..	..	..	..	..	+.02 W.	.00 W.
l Leonis	79	+30	..	..	..	..	..	..	..	..	..	..	..	−.06 E.	+.03 W.
α Ursæ Majoris	28	−22	..	..	..	..	..	..	..	..	..	..	..	+.12 E.	.00 W.
δ Leonis	60	+20	..	..	..	..	..	..	..	..	..	..	..	−.10 E.	..

	P. D.	Z. D.	May. 14	16	26	28	29	June. 1	11	13	14	16	17	18	19
	°	°													
δ Crateris	104	+55	..	−.01 E.	..	..	...	..	..	..	..	..	..		..
τ Leonis	6	+37	..	+.03 E.	..	..	..	..	..	..	..	..	..	..	..
λ Draconis	[illegible]	−29	..	−.14 E.	..	..	..	..	..	..	..	..	..	..	..
υ Leonis	9	+41	..	+.03 W.	..	..	..	..	..	..	..	..	..	..	..
β Leonis	75	+25	..	−.04 W.	..	..	..	..	..	..	..	..	..	..	..
γ Ursæ Majoris	36	−14	..	+.16 W.	..	..	..	..	..	..	..	..	..	..	..
η Virginis	90	+41	−.04 W.	..	..	..	..	..	..	..	..	..	..	..	..
κ Draconis	20	−40	−.02 W.	..	..	−.03 E.	..	..	..	..	..	..	..	..	..
32 H_2 Camelop	6	−43	..	..	..	..	+.02 W.	..	..	..	..	..	..	..	..
12 Canum ven	51	+ 2	..	..	..	+.03 E.	+.07 W.	..	..	+.03 E.	..	..	..	..	..
θ Virginis	95	+46	..	..	..	.00 E.	−.02 W.	..	..	−.03 E.	..	..	..	..	..
α Virginis	101	+46	+.04 W.	..	..	+.02 W.	−.09 E.	..	..	+.03 W.	..	..	..	..	..
ζ Virginis	90	+41	−.06 E.	..	..	−.02 W.	+.02 E.	..	..	.00 W.	..	+.01 E.	..	..	..
η Ursæ Majoris	40	− 9	+.02 E.	..	..	..	..	+.08 E.	−.06 W.	−.02 W.	−.04 W.	−.03 E.	..	+.08 E.	..
η Bootæ	71	+22	+.04 E.	..	..	..	..	−.08 E.	+.01 W.	..	+.03 W.	−.02 E.	..	.00 E.	..
α Draconis	25	−24	..	..	−.03 W.	..	..	.00 E.	..	..	rej.	−.01 E.	..	−.09 E.	..
α Bootæ	70	+21	..	..	+.06 W.	..	..	+.01 W.	+.04 E.	..	+.01 E.	..	+.06 W.	+.03 W.	+.10 W.
θ Bootæ	38	−12	..	..	+.06 W.	..	..	..	..	..	.00 E.	+.01 W.	−.06 W.	..	.00 W.
5 Ursæ Minoris	14	−35	..	..	..	..	..	−.03 W.	.00 E.	..	−.01 E.	.00 W.	.00 W.	..	−.02 W.
ε Bootæ	62	+13	..	..	−.08 E.	..	..	..	+.03 E.	..	..	+.02 W.	+.05 E.	..	−.08 E.
$α_2$ Libræ	106	+56	..	..	..	..	..	..	..	..	..	..	−.02 E.	..	−.03 E.
β Ursæ Minoris	15	−34	..	..	..	..	..	..	..	..	..	..	−.02 E.	..	+.03 E.

	P. D.	Z. D.	June. 20	22	23	25	27	29
	°	°						
α Virginis	101	+46	..	..	+.03 E.	..	..	..
ζ Virginis	90	+41	..	..	+.05 E.	..	..	..
η Ursæ Majoris	40	− 9	−.04 E.	..	−.08 E.	..	..	−.03 W.
η Bootæ	71	+22	+.03 E.	..	.00 W.	..	..	+.02 W.
α Draconis	25	−24	.00 E.	+.07 W.	.00 W.	..	−.16 E.	.00 E.
α Bootæ	70	+21	+.03 W.	−.04 W.	..	..	.00 E.	−.02 E.
θ Bootæ	38	−12	..	−.02 W.	..	..	+.10 E.	+.01 E.
5 Ursæ Minoris	14	−35	.00 W.	−.06 E.	..	..	.00 W.	..
ε Bootæ	62	+13	+.01 W.	+.01 E.	..	..	.00 W.	..
$α_2$ Libræ	106	+56	..	+.06 E.	..	..	..	..
β Ursæ Minoris	15	−34	..	..	..	..	..	..
$μ_1$ Bootæ	52	+ 3	..	..	..	−.06 W.	..	..
$γ_2$ Ursæ Minoris	18	−32	..	..	..	+.02 W.	..	..
α Coronæ Bor	63	+14	..	..	..	+.06 W.	..	..
α Serpentis	83	+34	..	..	..	+.06 E.	..	..
ε Serpentis	85	+36	..	..	..	−.05 E.	..	..
ζ Ursæ Minoris	12	−37	..	..	..	−.01 E.	..	..

Table of instrumental constants.

1877.		Level constant.		Azimuth.	Collimation.
March	1	+0.02 W.	+0.06 E.	−5.04	−0.36
	24	+0.01	+0.10	−2.40	0.00
April	6	−0.11	−0.03	−0.42	−0.17
	11	−0.02		+0.13	+0.20
	12	−0.04	+0.03	−0.20	+0.20
	17	−0.12	−0.04	+0.07	+0.22
	23	−0.10	−0.01	+0.04	+0.20
	24	−0.11	0.00	+0.05	+0.31
	25	0.00	+0.04	+0.22	+0.03
May	2	+0.16	+0.24	+0.71	+0.04
	3	+0.07	+0.08	+0.46	0.00
	7	−0.04	0.00	+0.59	+0.02
	12	+0.08	+0.10	+0.92	0.00
	14	+0.09	+0.10	−0.45	0.00
	16	+0.07	+0.13	−0.63	0.00
	26	+0.35	+0.34	+0.72	0.00
	28	+0.31	+0.36	+0.60	+0.04
	29	+0.36	+0.37	+0.47	−0.08

Table of instrumental constants—Continued.

1877.		Level constant.		Azimuth.	Collimation.
June	1	+0.38	+0.44	+0.66	0.00
	11	+0.26	+0.25	+0.56	0.00
	13	+0.22	+0.30	+0.55	—0.03
	14	+0.20	+0.28	+0.54	0.00
	16	+0.32	+0.35	+2.43	—0.03
	17	+0.44	+0.48	+0.33	+0.02
	18	+0.29	+0.38	+0.41	0.00
	19	+0.48	+0.50	+0.43	0.00
	20	+0.36	+0.38	+0.43	—0.05
	22	+0.54	+0.46	+0.30	—0.06
	23	+0.40	+0.40	+0.45	—0.02
	25	+0.31	+0.43	+0.31	+0.05
	27	+0.35	+0.54	+0.52	+0.06
	29	+0.43	+0.50	+0.47	+0.02

The chronometers were compared on the chronograph daily, and also before and after all pendulum-observations. The following table shows the results of these comparisons:

Mean time. Date.		Bond 387—Negus 1589		Bond 380—Negus 1589		Hutton 202—Negus 1589		Negus 1591 (red. to sid.)—Negus 1589	
1877.		*m.*	*s.*	*m.*	*s.*	*m.*	*s.*	*m.*	*s.*
March	1.41	+0	33.61	+0	25.06	+10	58.85	+0	49.34
	24.42	1	19.40	—0	6.55		57.00	1	8.38
	30.98		31.80		14.53	11	2.70		13.30
April	1.20		33.93		15.82		3.20		14.22
	6.38		43.13		21.46		6.36		17.10
	7.00		44.28		22.11		6.87		17.42
	7.20		44.63		22.30		7.10		17.47
	7.96		45.93		23.09		8.69		17.86
	8.05		46.10		23.21		8.80		17.90
	12.27		54.10		27.90		15.80		19.79
	13.06		55.76		29.81		17.09		18.48
	14.08		56.97		30.95		18.45		19.75
	16.18	2	2.41		35.84		24.60		18.13
	17.31		4.73		32.65		27.02		23.72
	19.03		8.77		33.23		31.37		24.22
	20.98		11.10		36.20		34.17		23.87
	23.28		15.99		38.69		38.51		24.64
	24.33		18.03		39.90		40.10		26.46
	25.20		19.80		40.41		41.45		18.53
	25.28		19.90		40.41		41.50		25.12
	26.26		21.74		41.48		42.90		25.20
	27.18		23.59		42.29		44.19		25.54
	28.04		24.97		43.06		45.11		25.65
May	1.21		29.22		46.95		47.40		24.90
	2.30		30.59		48.57		48.51		24.63
	3.29		32.09		50.02		49.69		24.74
	4.23		33.64		51.18		50.70		24.97
	5.24		35.34		52.36		50.04		25.24
	7.11		38.41		54.50		50.00		25.89
	7.32		38.58		54.85		49.79		25.75

Mean time. Date.		Bond 387—Negus 1589	Bond 380—Negus 1589	Hutton 202—Negus 1589	Negus 1591 (red. to sid.)—Negus 1589
1877.		m. s.	m. s.	m. s.	m. s.
May	7.48	+2 38.73	—0 54.97	+11 49.73	+1 25.76
	8.17	39.80	55.60	49.80	26.04
Chronometers (202) and (387) moved.					
May	8.22	39.40	55.62	49.80	26.04
	9.15	42.16	56.20	50.73	26.53
	10.12	44.92	57.02	51.92	26.84
	11.13	47.87	58.07	53.21	27.16
Chronometers moved.					
	11.23	50.20	56.08	55.33	29.22
	12.27	52.57	56.63	54.17	28.18
	14.35	Excesses over (387)	—3 55.20	+8 53.71	—1 31.45 ?
	14.54		55.80	52.58	32.11 ?
	15.26		57.93	50.00	34.90 ?
	16.31		4 0.86	45.80	37.54 ?
	17.99	+3 14.33	—0 50.75	+11 53.13	+1 30.75
	21.21	27.48	44.17	54.85	36.89
	24.16	33.16	42.64	52.18	31.47
	25.18	36.86	41.38	53.01	31.58
	26.21	40.18	40.32	53.64	31.41
	26.43	40.90	40.10	53.71	31.03
	28.32	47.16	38.17	55.01	31.30
	29.33	50.53	36.97	55.63	31.26
	31.23	57.00	34.30	56.60	31.42
June	1.35	4 1.14	32.46	56.72	31.49
	4.29	10.28	29.72	54.48	30.32
	8.29	21.70	25.60	53.43	27.85
	11.32	29.90	22.00	52.99	25.89
	11.49	30.30	21.90	52.90	25.70
	12.28	32.43	21.16	52.57	24.97
	13.27	35.03	20.37	52.09	24.36
	14.30	38.08	19.36	51.68	23.19
	14.48	38.60	19.20	51.58	23.00
	15.34	41.02	18.36	51.12	22.24
	15.47	41.35	18.22	51.06	22.08
	16.31	43.55	17.45	50.35	21.21
	16.43	43.89	17.31	50.22	21.09
	17.34	46.20	16.49	49.40	21.52
	17.49	46.58	16.28	49.28	
	18.32	48.60	15.67	48.10	19.22
	19.34	51.30	14.61	46.77	18.49
	19.46	51.68	14.42	46.68	18.30
	20.30	54.06	13.63	45.37	17.60
	20.40	54.38		45.30	17.59
	21.29	56.71	12.39	43.91	16.82
	22.31	59.42	11.78	42.22	15.76
	22.42	59.70	11.68	42.07	15.61
	23.28	5 2.10	11.20		14.63
	25.37	7.50	9.49	36.49	12.16

Mean time. Date.	Bond 387—Negus 1589	Bond 380—Negus 1589	Hutton 202—Negus 1589	Negus 1591 (red. to sid.)—Negus 1589
1877.	*m. s.*	*m. s.*	*m. s.*	*m. s.*
June 26.31	+5 9.82	−0 8.68	+11 34.28	+1 18.76
27.31	12.43	7.77	31.43	10.26
29.14	16.79	6.47	25.54	8.08
29.21	16.96	6.45	25.26	7.98
29.29	17.20	6.37	25.01	7.96
July 4.43	28.69	4.25	5.77	0.29

All the subsequent time-observations were made by Mr. Henry Farquhar, who was instructed to pursue the same system that Mr. Smith had done. For the experiments at various pressures with heavy end down, time-observations were begun on September 18, 1877, and continued till October 5, inclusive. The chronometer used was Negus 1589. The transits of the stars were taken as in Mr. Smith's observations, across the five wires of the middle group only, and read to twentieths of a second.

The observations taken from September 18 to 24 inclusive were not reduced, as the chronometer used in observation was suffered to run down on the 25th, by the janitor of the Stevens Institute, who had been commissioned to attend to winding it. The agreement of the stars observed, instrumental constants, and chronometer-comparisons are given in the following tables:

	P.D.	Z.D.	1877, September. 25	26	27	29	October. 1	5
	°	°						
ε Delphini	79	+30	..	..	+.01 W.	..	..	..
Gr. 3241	18	−31	..	..	+.07 W.	..	..	..
α Cygni	45	− 4	..	+.06 E.	−.10 W.	..	..	..
μ Aquarii	99	+50	..	−.06 E.	−.04 E.	..	..	..
ν Cygni	49	0	..	−.01 E.	..	..	..	..
12 Y. C. 1879	10	−39	..	..	−.05 E.	..	..	−.07 E.
61_1 Cygni	52	+ 3	..	+.04 W.	+.15 E.	+.05 E.	..	+.06 E.
ζ Cygni	60	+11	..	+.04 W.	..	+.05 E.	..	+.03 E.
α Cephei	28	−21	..	−.06 W.	..	−.10 E.	..	−.04 W.
1 Pegasi	71	+21	..	..	..	rej.	..	−.02 W.
β Aquarii	96	+47	−.02 W.	..	..	−.09 W.	..	−.05 W.
β Cephei	20	−29	+.06 W.	..	..	+.08 W.	..	+.07 W.
ξ Aquarii	98	+49	..	..	..	+.11 W.	..	..
ε Pegasi	81	+31	+.02 W.	..	..	−.05 W.	..	..
11 Cephei	19	−30	−.05 W.	..	..	..	..	..
79 Draconis	17	−32	−.01 E.	..	..	..	+.05 W.	..
α Aquarii	91	+42	rej.	..	..	..	−.01 W.	..
θ Aquarii	98	+49	−.01 E.	..	..	..	−.01 W.	..
κ Aquarii	89	+40	..	..	..	..	−.01 E.	..
η Aquarii	91	+41	..	..	..	..	+.04 E.	..
226 B Cephei	14	−35	..	..	..	..	−.05 E.	..

	P.D.	Z.D.	October. 5
	°	°	
α Orionis	83	+33	−.03 W.
22 H Camelop	21	−29	+.03 W.
μ Geminorum	67	+18	−.06 W.
γ Geminorum	73	+24	+.22 E.
α Canis Majoris	107	+57	−.19 E.
51 H Cephei	3	−46	.00 E.

Instrumental constants.

	Level constant.		Azimuth.	Collimation.
September 25	−0.88 W.	−0.80 E.	+0.53	−0.03
26	+0.30 W.	+0.38 E.	+0.31	−0.03
27	+0.33 W.	+0.47 E.	+0.42	+0.16
29	+0.41 W.	+0.49 E.	+0.39	+0.16
October 1	+0.44 W.	+0.50 E.	+0.33	+0.10
5	+0.57 W.	+0.62 E.	+0.23	+0.14
5	+0.62 W.	+0.65 E.	+0.48	+0.02

Comparison of chronometers.

1877.		Seconds of excess of Bond & Son 380 ove Hutton 202.	Negus 1589.	Negus 1591, *reduced.*
		s.	*s.*	*s.*
September	18.29:	33.80	30.40	
	21.38:	43.23	52.43	
	22.36:	48.26	50.45	
	23.26:	53.30	48.91	
	24.38:	59.88	46.93	
		Chronometer ran down.		
	25.41	5.53	15.20	
	26.32	10.99	14.28	
	26.52	11.96	14.01	
	27.32	16.80	13.23	
	27.44	17.46	13.13	27.61
	29.34	28.62	11.17	25.22
	29.77	30.68	10.27	24.45
	29.83	30.98	10.17	24.43
October	1.34	37.29	7.34	23.34
	1.43	39.82	7.21	23.31
	1.73	41.71	6.92	23.35
	1.79	42.20	6.89	23.38
	3.33	51.54	5.41	
	3.57	53.96	5.11	23.71
	3.80	54.55	4.83	23.71
	5.32	4.41	2.68	23.27
	5.76	6.89	1.79	23.12

Time-observations for the experiments at various pressures with heavy end up were made, 1877, November 30 to December 24, inclusive. The chronometer used was Bond and Sons 380. In reducing these observations, the value of the azimuth was taken different in the two positions of the transit-instrument, and the observations of single stars received weights varying with the declination, in accordance with the latest recommendations of the Computing Division.

	P. D.	Z. D.	1877, December. 2
	°	°	
κ Aquarii	89	+40	−.03 E.
η Aquarii	91	+41	+.03 E.
226 B Cephei	14	−35	+.02 E.
ζ Pegasi	80	+31	+.01 W.
ι Cephei	24	−25	.00 W.
λ Aquarii	98	+49	−.01 W.

	P. D.	Z. D.	December. 16	24
	°	°		
α Pegasi	75	+26	..	−.08 E.
ο Cephei	23	−27	..	.00 E.
θ Piscium	84	+35	..	+.25 E.
ι Piscium	85	+36	−.01 W.	.00 W.
γ Cephei	13	−36	+.11 W.	+.03 W.
Gr. 4163	16	−33	−.11 W.	−.09 W.
ω Piscium	84	+35	+.03 W.	+.01 W.
α Andromedæ	62	+12	+.21 E.	..
γ Pegasi	76	+26	−.20 E.	..
α Cassiepeæ	34	−15	.00 E.	..

	P. D.	Z. D.	November. 30	December. 3	10	23
	°	°				
ο Piscium	81	+32	..	..	..	−.06 W.
β Arietis	70	+21	..	−.09 W.	..	+.06 W.
50 Cassiepeæ	18	−31	..	−.06 W.	..	.00 W.
α Arietis	67	+18	..	..	..	−.02 E.
ξ_1 Ceti	82	+32	+.12 E.	+.10 W.	..	+.01 E.
ι Cassiepeæ	23	−26	−.03 E.	+.14 E.	..	−.01 E.
γ Ceti	87	+38	−.10 E.	+.01 E.	..	..
α Ceti	86	+37	−.09 W.	..	−.01 E.	..
48 H Cephei	13	−37	..	−.06 E.	..	..
ζ Arietis	69	+20	..	−.05 E.	.00 E.	..
α Persei	41	− 9	..	..	.00 E.	..
δ Persei	43	− 7	+.02 W.	..	−.01 W.	..
η Tauri	66	+17	+.06 W.	..	+.05 W.	..
ζ Persei	58	+ 9	..	..	−.02 W.	..
γ_1 Eridani	104	+55	..	..	.01 W.	..

	P.D.	Z.D.	December. 7	9	12	14	17	20
	°	°						
γ Tauri	75	+25	−.08 E.	..	..	..	..	..
ε Tauri	71	+22	+.04 E.	..	..	..	..	..
α Tauri	74	+24	+.04 E.	.00 W.	..	+.04 E.	+.01 E.	..
9 Camelop	24	−25	.00 E.	.00 W.	+.01 W.	+.04 E.	+.02 E.	..
ι Aurigæ	57	+ 8	−.01 W.	−.01 W.	−.06 W.	−.09 E.	−.01 E.	..
11 Orionis	75	+26	..	+.08 E.	+.07 W.	.00 W.	+.08 W.	..
α Aurigæ	44	− 5	..	.00 E.	−.04 E.	+.02 W.	−.04 W.	..
β Orionis	98	+49	..	−.08 E.	−.03 E.	+.02 W.	−.05 W.	..
β Tauri	61	+12	..	..	+.07 E.	..	..	+.02 W.
Gr.966	15	−34	..	..	..	..	..	+.01 W.
δ Orionis	90	+41	..	..	..	..	..	.00 W.
α Orionis	83	+33	..	..	..	..	..	+.12 E.
22 H Camelop	21	−29	..	..	..	..	..	−.01 E.
μ Geminorum	67	+18	..	..	..	..	..	−.14 E.

	P.D.	Z.D.	December. 22
	°	°	
δ Geminorum	68	+19	−.13 E.
P. VII 67	21	−28	−.01 E.
α Geminorum	58	+ 9	+.11 E.
α Canis Min	84	+35	−.23 W.
β Geminorum	62	+12	+.16 W.
φ Geminorum	63	+14	+.05 W.
3 H Ursæ Maj	21	−28	+.02 W.

	P.D.	Z.D.	November. 30
	°	°	
l Leonis	79	+30	.00 W.
α Ursæ Maj	28	−22	+.05 W.
δ Leonis	69	+20	−.04 W.
δ Crateris	104	+55	+.12 E.
λ Draconis	20	−29	−.03 E.
υ Leonis	90	+41	−.10 E.

Instrumental constants.

1877.	Level constant.		Azimuth.		Collimation.
November 30	−0.03 W.	−0.01 E.	+0.15		+0.02
30	−0.08 W.	−0.04 E.	−0.07		+0.01
December 2	−0.05 W.	0.00 E.	−0.24 W.	+0.21 E.	0.00
3	−0.13 W.	−0.08 E.	+0.35		+0.05
7	−0.08 W.	−0.05 E.	+0.04		+0.09
9	−0.07 W.	−0.04 E.	+0.35 W.	+0.03 E.	−0.14
10	−0.17 W.	−0.07 E.	−0.02 W.	−0.20 E.	+0.12
12	−0.12 W.	−0.03 E.	−0.09 W.	+0.08 E.	−0.02
14	−0.06 W.	−0.02 E.	+0.04 W.	−0.36 E.	+0.13
16	−0.14 W.	−0.03 E.	−0.12 W.	−0.76 E.	+0.11
17	−0.19 W.	−0.10 E.	−0.23		+0.14
20	−0.01 W.	+0.01 E.	−0.06 W.	+0.15 E.	+0.15
22	−0.06 W.	+0.04 E.	0.00 W.	+0.19 E.	+0.19
23	+0.04 W.	+0.07 E.	+0.34 W.	−0.01 E.	+0.13
24	+0.02 W.	+0.03 E.	−0.02		+0.06

Comparison of chronometers.

1877.		Seconds of excess of Bond & Sons 380 over Hutton 202.	Negus 1589.	Negus 1591, *reduced.*
		s.	*s.*	*s.*
November	30.50	37.41	19.77	10.26
	30.80	38.61	18.86	9.89
December	2.27	44.11	13.28	7.62
	3.43	48.19	8.90	6.15
	4.45	52.19	5.31	4.68
	7.57	5.06	54.87	0.87
	8.37	8.64	51.84	59.78
	8.86	10.66	50.31	59.23
	9.43	12.85	48.35	58.26
	10.47	16.59	44.70	57.07
	10.83	17.96	43.50	56.73
	12.46	24.70	38.37	55.01
	12.79	26.11	37.41	54.70
	14.44	32.72	32.13	52.92
	14.81	34.19	30.88	52.50
	16.22	39.30	25.99	51.00
	16.51	40.38	25.01	50.26
	17.43	43.82	21.90	49.17
	17.79	45.10	20.70	48.78
	19.52	51.21	14.70	46.60
	19.82	52.38	13.71	46.31
	20.47	54.90	11.48	45.59
	22.53	2.15	3.88	42.14
	22.85	3.47	2.84	41.68
	23.17	4.61	1.70	41.21
	23.51	5.83	0.49	40.68
	24.19	8.15	57.76	39.29

The time-observations for the experiments at high temperatures and for the investigations to determine if the chronometers had any diurnal inequality of rate extended from 1878, February 19 to May 23 inclusive. The observation of May 21 is not reduced: on account of the discordance of the separate stars, no values for the time-correction and instrumental constants were resolved upon.

	P. D. °	Z. D. °	1878, February 24
α Orionis	83	+33	−.03 E.
22 H Camelop	21	−29	−.02 E.
μ Geminorum	67	+18	+.01 E.
γ Geminorum	73	+24	+.02 W.
α Canis Majoris	107	+57	−.01 W.
51 H Cephei	3	−46	+.07 W.

	P. D. °	Z. D. °	February 19	February 27	March 5	April 2	April 14
ι Ursæ Majoris	41	− 8	..	+.08 W.	..	..	..
σ_2 Ursæ Majoris	22	−27	..	−.10 W.	..	.00 W.	..
κ Cancri	79	+30	..	+.01 W.	..	.00 W.	..
1 H Draconis	8	−41	..	−.01 E.	−.12 E.	−.25 E.	+.23 W.
α Hydræ	98	+49	+.05 W.	−.02 E.	−.02 E.	−.10 E.	+.02 W.
d Ursæ Majoris	20	−30	.00 W.	+.05 E.	+.14 E.	+.15 E.	+.19 W.
θ Ursæ Majoris	38	−11	+.01 W.	−.02 E.	−.02 E.	+.08 E.	−.15 W.
ε Leonis	66	+16	−.06 W.	..	+.02 W.	..	−.09 E.
μ Leonis	63	+14	+.10 E.	..	+.02 W.	..	+.07 E.
α Leonis	77	+28	−.10 E.	..	−.06 W.	..	..
32 Ursæ Majoris	24	−25	−.01 E.	.	.00 W.	..	..

	P. D. °	Z. D. °	March 19	March 29	April 6	April 18	May 5
γ_1 Leonis	69	+20	..	..	−.01 W.	..	..
9 H Draconis	14	−36	.00 W.	..	−.01 W.	..	..
ρ Leonis	80	+31	−.10 W.	..	.00 W.	..	..
l Leonis	79	+30	+.11 W.	−.01 E.	.00 E.	..	..
α Ursæ Majoris	28	−22	.00 E.	.00 E.	.00 E.	+.06 E.	..
δ Leonis	69	+20	.00 E.	+.02 E.	..	+.03 E.	+.03 E.
δ Crateris	104	+55	..	+.09 W.	..	−.09 E.	−.03 E.
τ Leonis	86	+37	..	−.09 W.	..	+.11 W.	+.01 E.
λ Draconis	20	−29	..	+.02 W.	..	−.06 W.	−.01 E.
υ Leonis	90	+41	..	..	..	−.06 W.	−.01 W.
β Leonis	75	+25	..	..	..	..	+.01 W.
γ Ursæ Majoris	36	−14	..	..	..	..	−.03 W.

	P. D. °	Z. D. °	1878, April 3	April 8	May 2	May 6	May 8	May 9	May 10	May 11	May 13	May 13	May 22	May 23
β Leonis	75	+25	−.01 E.	..	..	..	..	..	..	..	..	..	..	..
γ Ursæ Majoris	36	−14	.00 E.	..	..	..	..	..	..	..	..	..	..	..
o Virginis	81	+31	..	..	−.04 W.	..	.00 E.	..	..	..	..	..	..	..
4 H Draconis	12	−38	..	..	−.03 W.	..	−.01 E.	..	..	..	..	..	..	..
η Virginis	90	+41	.00 W.	..	..	..	.00 E.	..	..	..	..	..	..	..
β Corvi	113	+63	..	..	+.09 W.	..	+.03 W.	..	..	..	..	..	..	..
κ Draconis	20	−30	+.01 W.	..	..	..	..	..	..	..	..	..	.	..
32 H_2 Camelop	6	−43	..	..	+.06 E.	+.01 W.	..	..	..	..	..	..	..	..
12 Canum Ven	51	+ 2	..	..	−.32 E.	+.01 W.	−.01 W.	..	..	..	..	..	..	..
ϑ Virginis	95	+46	..	+.01 E.	+.04 E.	−.05 W.	..	..	..	..	..	..	+.06 E.	..
α Ursæ Min. (L.C.)	−1	−51	..	−.05 E.	..	..	..	..	..	..	..	..	..	..
α Virginis	101	+51	..	..	+.04 E.	+.03 E.	..	..	..	..	−.02 E.	..	−.12 E.	−.03 W.
ζ Virginis	90	+41	..	−.03 W.	..	+.05 E.	..	..	..	..	+.02 E.	..	+.05 E.	+.04 W.
η Ursæ Majoris	40	− 9	..	+.01 W.	..	.00 E.	..	..	..	..	.00 E.	..	−.01 E.	−.01 W.
η Bootæ	71	+22	..	..	..	..	..	..	..	..	+.08 W.	..	+.02 W.	+.05 E.
α Draconis	25	−24	..	..	..	..	..	..	..	..	+.01 W.	..	+.01 W.	+.02 E.
α Bootæ	70	+21	..	..	..	..	..	..	..	..	−.06 W.	..	−.01 W.	−.04 E.
θ Bootæ	38	−12	..	..	..	..	..	..	..	..	..	+.11 W.	..	..
5 Ursæ Minoris	14	−35	..	..	..	..	..	..	..	..	..	−.13 W.	..	..
ε Bootæ	62	+13	..	..	..	..	..	..	..	..	..	−.06 W.	..	..
α_2 Libræ	106	+56	..	..	..	..	..	..	..	..	..	−.03 E.	..	..
β Ursæ Minoris	15	−34	..	..	..	..	..	−.01 W.	..	..	..	+.03 E.	..	..
β Bootæ	49	0	..	..	..	..	..	..	..	..	..	−.03 E.	..	..
β Libræ	99	+50	..	..	..	..	..	−.02 W.	..	.00 W.	..	..	..	..
μ_1 Bootæ	52	+ 3	..	..	..	..	..	+.02 E.	+.01 E.	−.02 W.	..	..	..	..
γ_2 Ursæ Minoris	18	−32	..	..	..	..	..	.00 E.	.00 E.	+.01 W.	..	..	..	..
α Coronæ	63	+14	..	..	..	..	..	+.05 E.	.00 E.	+.07 E.	..	..	..	..
α Serpentis	83	+34	..	..	..	..	..	−.07 E.	−.06 W.	+.05 E.	..	..	..	..
ε Serpentis	85	+36	..	..	..	..	..	..	+.07 W.	−.09 E.	..	..	..	..
ζ Ursæ Minoris	12	−37	..	..	..	..	..	..	+.01 W.	.00 E.	..	..	..	..

Instrumental constants.

1878.		Level constant.		Azimuth.		Collimation.
February	19	+0.17 W.	+0.23 E.	+0.25 W.	−0.22 E.	+0.11
	24	+0.74 W.	+0.84 E.	−0.13 W.	−0.38 E.	+0.12
	27	+0.72 W.	+0.80 E.	−0.37		+0.13
March	5	+0.78 W.	+0.78 E.	+0.15 W.	−0.25 E.	+0.07
	19	+0.86 W.	+0.94 E.	−0.31 W.	+0.22 E.	+0.03
	29	+0.85 W.	+0.97 E.	+0.24 W.	−0.38 E.	+0.09
April	2	+0.78 W.	+0.82 E.	−0.41 W.	−0.22 E.	+0.12
	3	+0.73 W.	+0.87 E.	−0.17 W.	−0.47 E.	+0.18
	6	+0.79 W.	+0.88 E.	−0.21 W.	−0.02 E.	+0.06
	8	+0.79 W.	+0.90 E.	−0.22		+0.22
	14	+0.86 W.	+0.96 E.	−0.08		+0.19
	18	+0.87 W.	+0.93 E.	−0.08		+0.17
May	2	−0.24 W.	−0.14 E.	−0.05		+0.20
	5	−0.01 W.	+0.02 E.	−0.27 W.	−0.09 E.	+0.05
	6	−0.12 W.	−0.07 E.	−0.04 W.	−0.33 E.	+0.02
	8	−0.21 W.	−0.13 E.	−0.02		+0.04
	9	−0.08 W.	−0.02 E.	+0.17 W.	+0.04 E.	−0.04
	10	−0.04 W.	−0.01 E.	+0.03 W.	−0.30 E.	+0.15
	11	−0.06 W.	+0.04 E.	+0.21 W.	+0.03 E.	+0.03
	13	−0.12 W.	−0.10 E.	+0.21		−0.04
	13	−0.14 W.	−0.04 E.	+0.06		−0.08
	21	−0.32 W.	−0.20 E.			
	22	−0.21 W.	−0.11 E.	+0.14 W.	−0.21 E.	+0.05
	23	−0.25 W.	−0.17 E.	−0.18		+0.11

Comparisons of chronometers.

1878.		Seconds of excess of Bond & Sons 380 over Hutton 202.	Negus 1589.	Negus 1591, *reduced.*
		s.	*s.*	*s.*
February	19.52		39.39	
	24.30	55.83	35.72	51.67
	27.43	11.50	29.28	
March	5.42	37.56	11.89	34.74
	19.48	39.72	40.06	11.42
	29.46	31.03	21.40	59.94
April	2.38	47.65	24.96	55.35
	3.40	52.44	12.15	54.11
	6.43	10.12	7.39	51.55
	8.48	17.31	0.39	45.74
	14.31	49.18	51.02	41.22
	18.43	10.36	46.14	38.95
	24.42	35.01		34.73
	26.37	42.60	37.98	32.70
	26.54	43.33	37.21	32.56
	30.37	4.39	32.90	29.87
	30.63	5.89	32.69	29.83
May	1.16	8.80	32.16	29.57
	1.38	13.30	31.15	29.13
	2.16	14.26	30.90	
	2.35	15.27	30.76	30.95
	2.94	18.32	30.21	28.71
	4.02	23.99	29.38	28.67

1878.		Excess of Bond & Sons 380 over Hutton 202.	Negus 1589.	Negus 1591, *reduced.*
		s.	*s.*	*s.*
May	4.21	24.95	29.17	28.60
	4.39	25.85	29.00	28.41
	4.48	26.38	28.92	28.39
	5.34	30.61	28.18	28.33
	5.47	31.24	28.05	28.16
	5.91	33.39	27.65	28.07
	5.99	33.73	27.53	28.00
	6.18	34.58	27.33	27.91
	6.46	35.88	27.95	28.74
	6.54	36.23	28.13	28.92
	6.97	38.42	28.99	28.78
	7.20	39.85	29.43	28.59
	7.96	44.59	28.59	28.32
	8.20	45.94	28.30	28.23
	8.36	46.85	28.13	28.20
	8.49	47.66	27.99	28.16
	8.98	50.53	27.37	28.06
	9.18	51.66	27.01	27.96
	9.48	53.35	26.64	28.56
	9.99	56.15	25.90	28.37
	10.39	58.23	25.18	28.13
	10.50	58.81	24.99	28.10
	11.00	1.39	24.03	27.69
	11.38	3.24	23.25	27.36
	11.48	3.70	23.04	27.27
	13.39	11.24	19.02	25.56
	13.50	11.64	18.79	25.46
	16.87	23.84	11.25	22.11

During all the pendulum-experiments, except those of September and October in 1877, the chronometers were wound at two different times of day,

Hutton 202 and Bond & Sons 380 at about 8 a. m., and
Negus 1589 and 1591 at 4 to 5 p. m.

A series of special comparisons between these chronometers was made after the completion of the pendulum-work, to ascertain if any diurnal correction, consequent on the time of winding, existed. It will be seen from the following table, and the illustration hereafter to be explained, that there is no such correction to be found.

Comparison of chronometers.

1878.		Seconds of excess of Bond & Sons 380 over Hutton 202.	Negus 1589.	Negus 1591, *reduced.*
		s.	*s.*	*s.*
May	16.87	23.84	11.25	22.11
	21.41	42.63	3.19	19.09
	21.48	42.96	3.10	19.07
	21.89	44.94	2.58	18.97
	22.01	45.70	2.36	18.86
	22.15	46.52	2.14	18.77
	22.23	46.99	2.01	18.72
	22.36	47.80	1.80	18.64
	22.47	48.44	1.64	18.59
	22.89	50.76	0.97	18.38
	23.02	51.41	0.72	18.26
	23.13	51.98	0.54	18.20
	23.23	52.50	0.39	18.12
	23.37	53.39	0.16	18.03
	23.49	54.14	59.98	17.94
	23.90	56.59	59.26	17.71
	24.02	57.22	59.06	17.66
	24.13	57.86	58.89	17.61
	24.22	58.06	58.54	17.33
	24.36	58.14	57.54	16.47
	24.47	58.19	56.75	15.79
	24.88	0.47	56.10	15.61
	25.02	1.21	55.87	15.51
	25.12	1.79	55.73	15.44
	25.22	2.34	55.60	15.40
	25.36	3.15	55.44	15.34
	25.49	3.92	55.30	15.31
	26.90	12.35	53.77	14.88
	27.02	13.02	53.61	14.82
	27.19	13.97	53.43	14.77

Rates of chronometers graphically represented.

Illustrations Nos. 31, 32, 33, 34, and 35 show these comparisons, with the corrections of the chronometers, as graphically represented. From the comparisons made at the time of the transit-observations, the correction of each chronometer is deduced; an approximate mean uniform rate is then applied to each, and the excess of the correction over this mean rate plotted. It is then determined by inspection which chronometer is going most nearly uniformly, between one set of star-observations and the next, and this chronometer is taken as a standard. The rates of the other chronometers, from comparison to comparison, are taken as given by the supposition of its entire uniformity. The comparisons made a few hours apart, at the beginning and end of each day's pendulum-work, are not combined for a definitive rate of the chronometer used, however; their chief service is in guarding against any sudden change of rate. The comparisons made at the time of the star-observations are distinguished by a circle on the illustrations.

1877. *Experiments in June. Illustration No.* 31.—The chronometer whose rate was most nearly uniform during this month was found to be different at different times. The following were found to be best in this respect:

	Best chronometer.
June 1 to 14	202
14 to 16	380
16 to 19	1589
19 to 22	1591
22 to 29	1589

The subjoined table gives the rates adopted for the chronometers used in the experiments, as found on these assumptions:

	Chronometer used.	Rate in seconds.	In decimals of a day.
		s.	
June 11	380	−0.49	−.00000057
11	202	+0.81	+ 094
14	387	−2.49	− 288
15	380	−0.59	− 068
16	380	−0.59	− 068
17	202	+1.23	+ 142
19	202	+2.07	+ 240
20	202	+2.07	+ 240
22	202	+2.90	+ 336
29	202	+3.68	+ 426

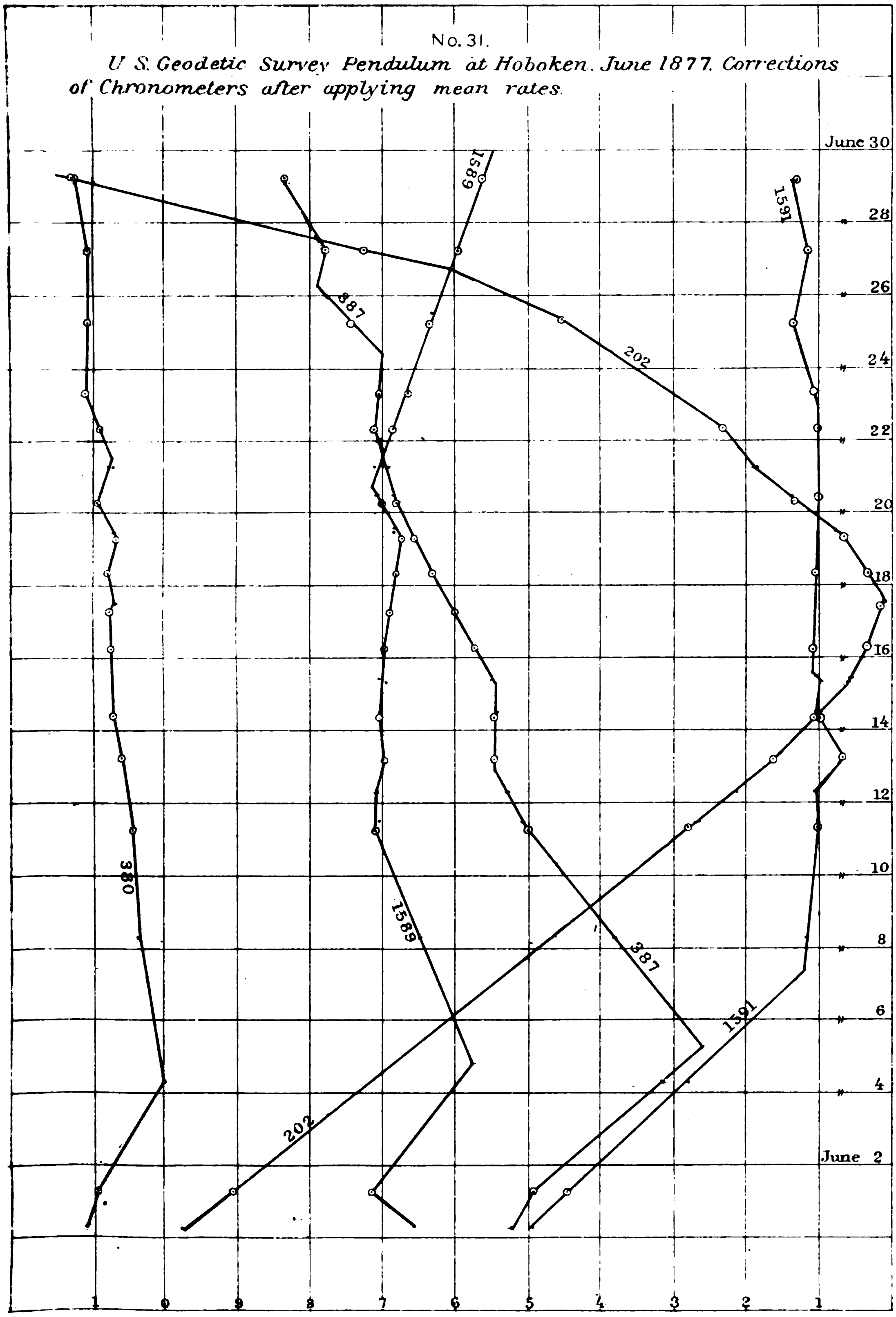
1877. *Experiments in September and October. Illustration No.* 32.—A uniform rate of $-0^s.91$ for chronometer 1589 from the beginning to the end of the experiments was taken, and the following rates of the chronometer used (No. 380) during each night of pendulum-work thus deduced.

	Rate in seconds.	Rate in decimals of a day.
	s.	
September 25	+0.11	+.0000013
26	+0.11	013
27	+0.11	013
29	+1.10	128
October 1	+0.08	009
3	+0.08	009
5	+1.11	129

1877. *Experiments in December. Illustration No.* 33.—Chronometer 202 was found to have a uniform rate of $+7^s.225$ from the beginning until December 11.7, then a uniform rate of $+6^s.813$ until the transit-observations of the 20th. After the 20th, No. 380 was itself adopted as the standard.

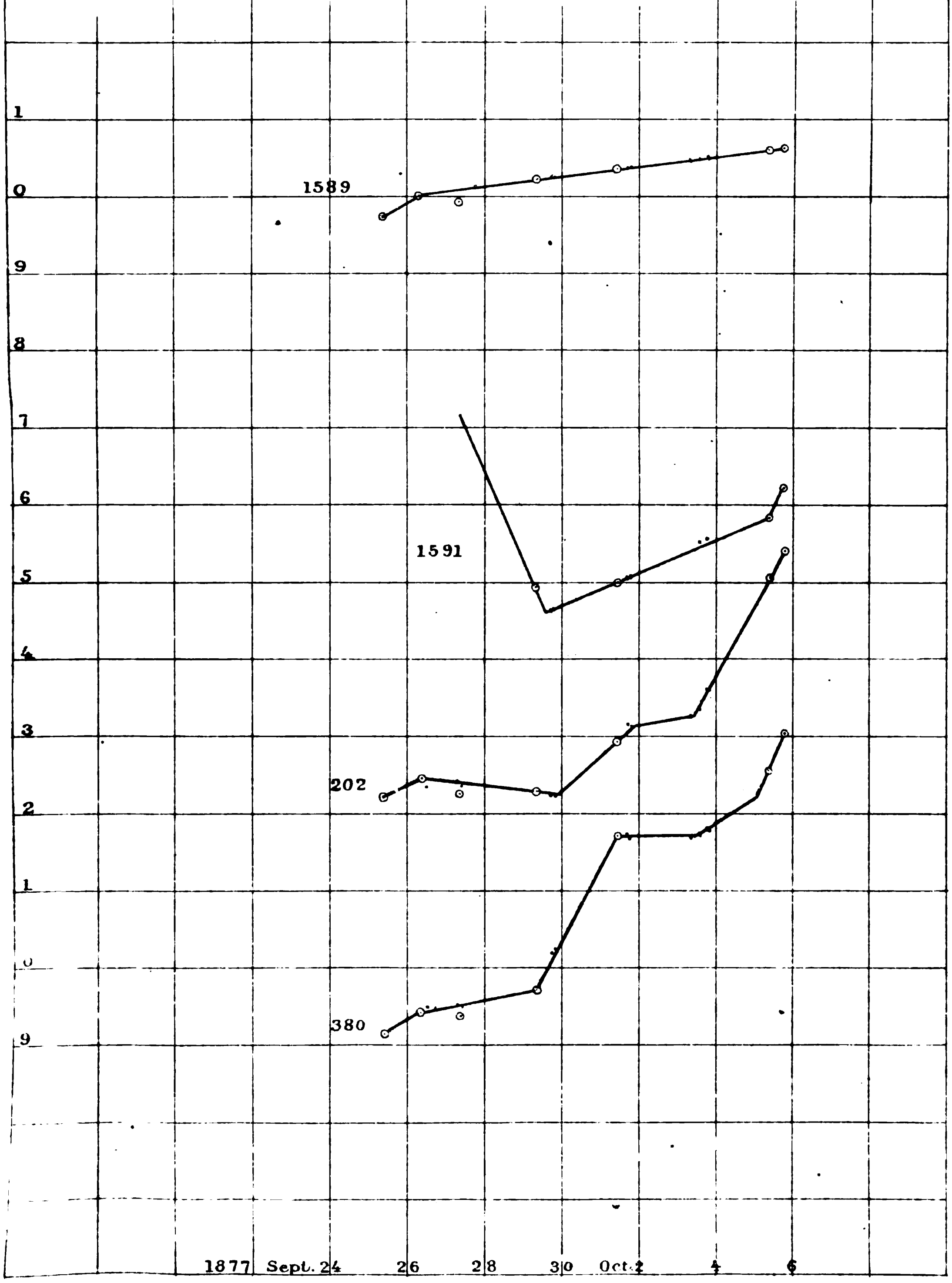
Rate of chronometer 380.

	s.	Decimal of a day.
November 30	+3.17	+.0000367
December 4	3.19	369
8	3.05	353
10	3.36	389
12	2.45	283
14	2.84	329
16	3.08	356
17	3.25	376
19	2.89	335
22	3.51	406
23	3.51	406


No. 31.
U. S. Geodetic Survey Pendulum at Hoboken. June 1877. Corrections of Chronometers after applying mean rates.
June 30
28
26
24
22
20
18
16
14
12
10
8
6
4
June 2
1589
1591
387
202
380
1589
387
1591
202
1
0
9
8
7
6
5
4
3
2
1

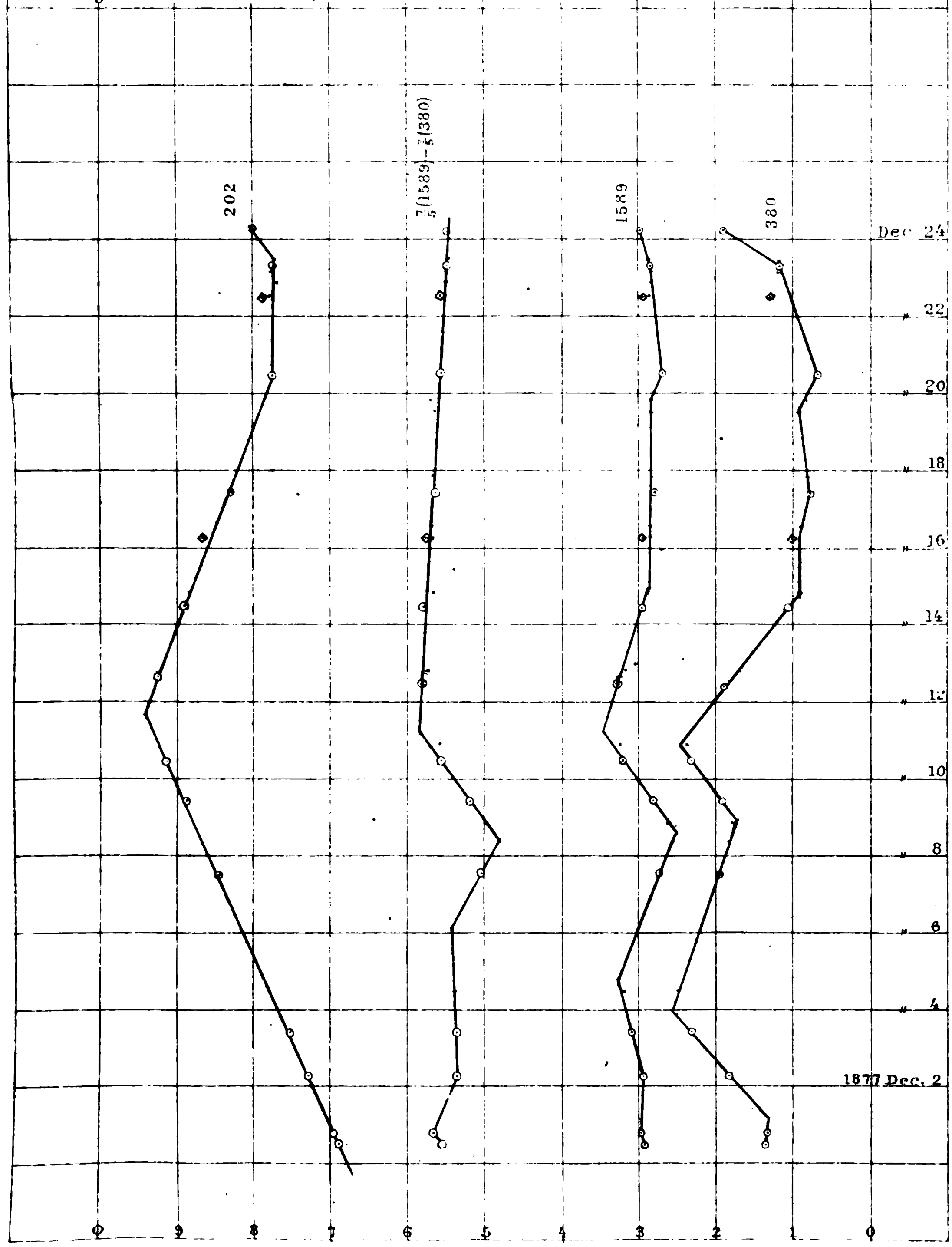
No. 32.

U. S. Geodetic Survey Pendulum at Hoboken. Experiments at Varying Pressures. Corrections to Chronometers after applying uniform rates.



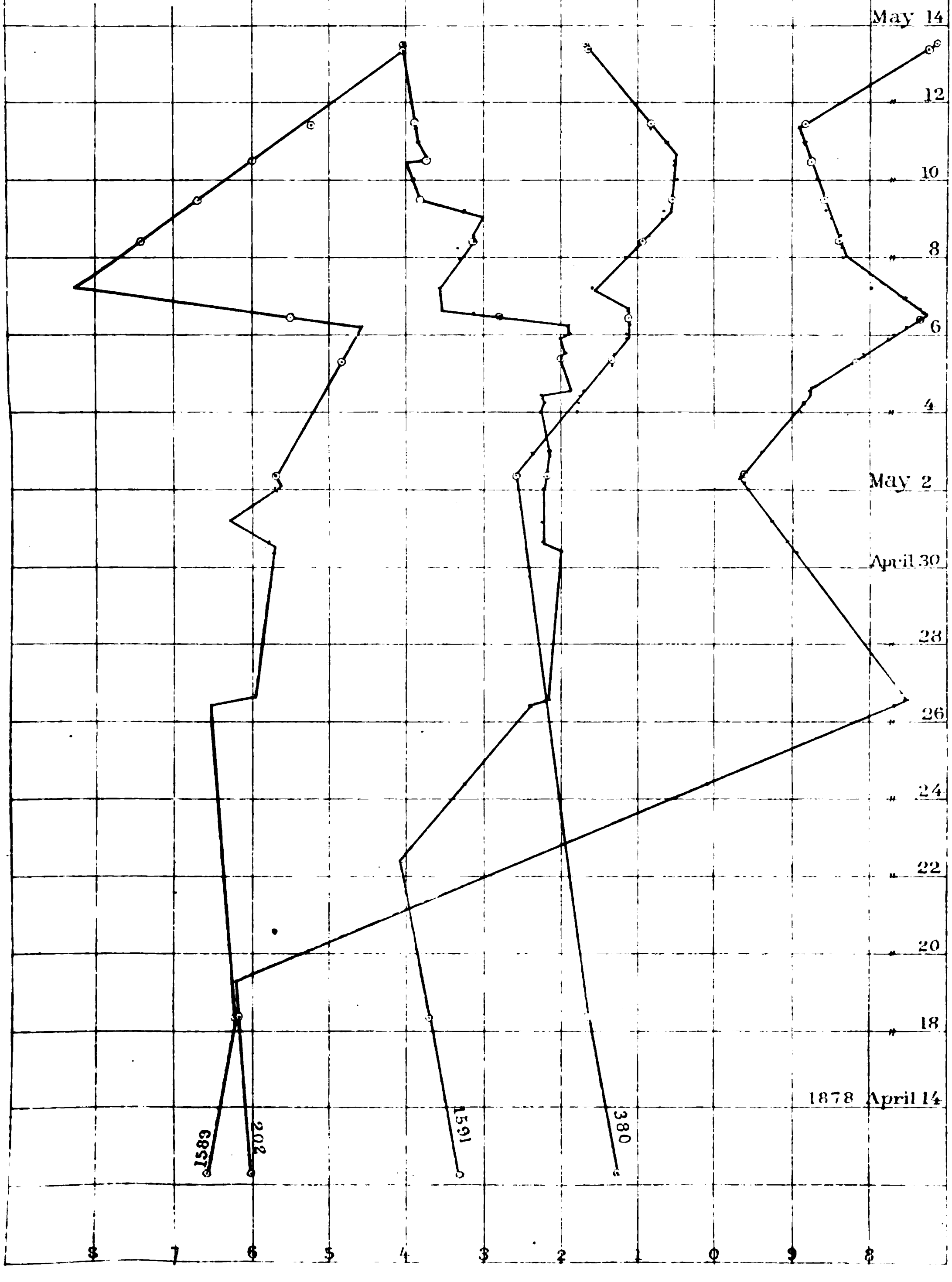
No. 33.

U. S. Geodetic Survey Pendulum at Hoboken. Experiments at different Pressures. Correction of Chronometers, after applying uniform rates. (Star obs. of the 16th and 22nd thought to be not so good as the others)



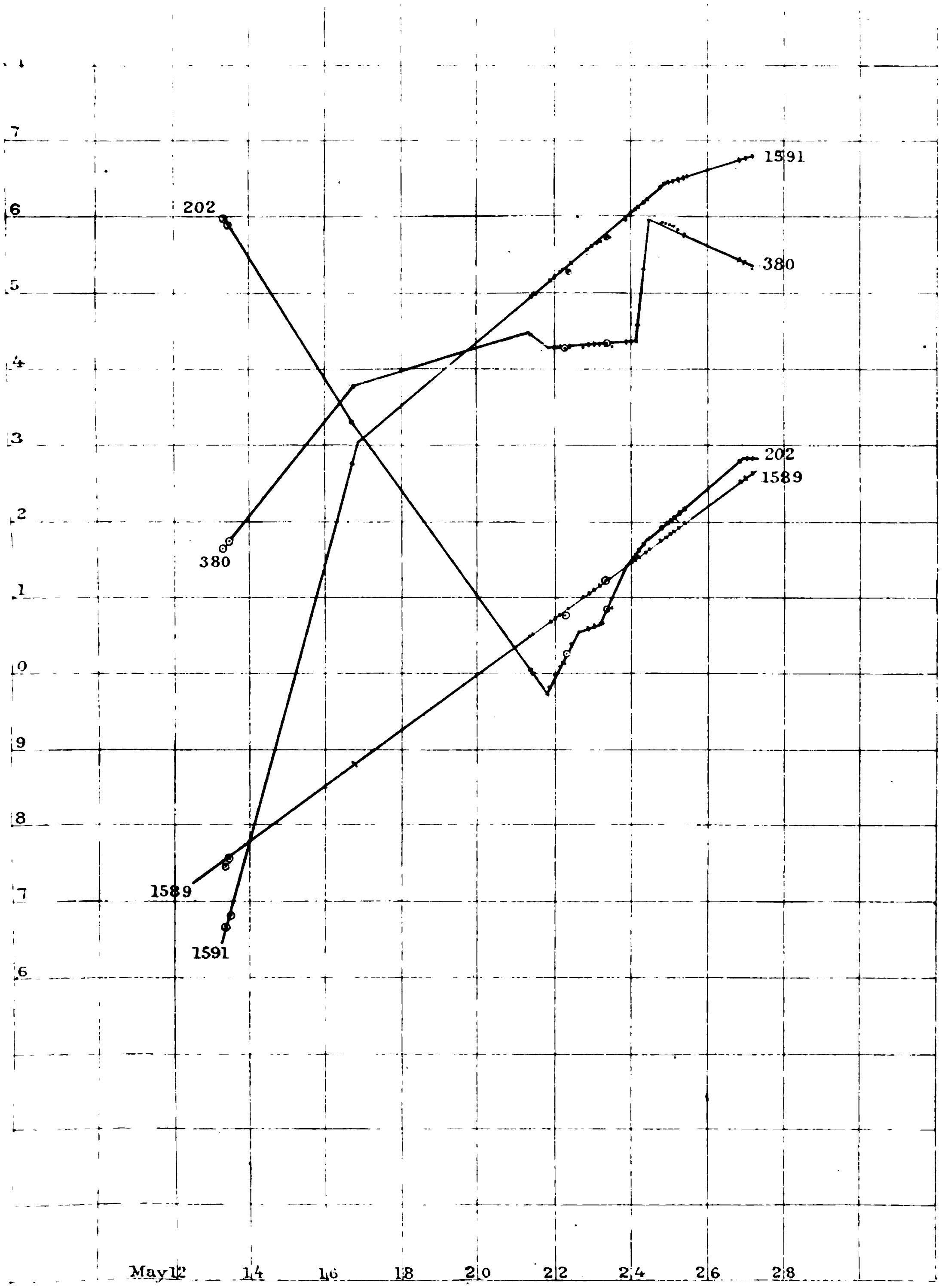
No. 34.

U. S. Geodetic Survey Pendulum at Hoboken. Experiments at High Temperatures. Corrections of Chronometers after application of uniform rates.



No. 35.

1878. Observations for Diurnal Variation of Rate of Chronometers.



1878. *Experiments in April and May. Illustration No.* 34.—Before heating up the room in which the pendulum was swung the chronometers were moved outside, to a place which was not so favorable in uniformity of temperature and in other respects. Their rates were therefore not so good as they had previously been. Chronometer 1589 was taken as the standard, and supposed to run uniformly until the 2d, and from the 2d to the 5th of May. Between the 5th and the 9th there were evidently two changes of rate; the times when these occurred were determined from the comparisons with the other chronometers. The rate was uniform again from the 9th to the 13th.

	Rate of 1589.
	s.
April 18.43 to 32.35	+1.036
May 2.35 to 6.18	+1.29
6.18 to 7.20	−2.52
7.20 to 13.50	+1.667

The rates of No. 380 during the nights of pendulum-work were then found to be—

	Rate in seconds.	In decimals of a day.
April 24	+0.07	+.0000008
26	+0.07	+ 008
30	−0.08	− 009
May 2	−0.39	− 045
4	−0.39	− 045
5	−0.39	− 045
6	+0.47	+ 054
8	−0.51	− 059
10	+0.24	+ 028
11	+0.24	+ 028

CORRECTION FOR ARC.

The factor for reducing the time of oscillation of the pendulum to an infinitesimal arc is best developed according to powers of the arc itself. Such a development is far more convergent than those found in the books. The factor is

$$1 - \frac{1}{64} A^2 + \frac{1}{49152} A^4 - \frac{5}{1179648} A^6 + \text{etc.},$$

where A represents the whole amplitude of the oscillation expressed in parts of the radius.

The Repsold pendulum tripod is provided with a metallic arc for reading the amplitude of oscillation. This is divided into spaces of 10′ each. In the experiments on the Geneva support an arc divided into thousandths of the radius was made use of.

At Geneva, the amplitude was read by bringing the vertical wire of the telescope so as to bisect the point of the pendulum at the extremity of an oscillation, the wire having been turned in a direction radial from the line of the knife-edge. The time was noted and the position of the wire between two lines of the graduated arc was estimated at leisure. At the other stations a far better method was used. The wire was placed in exact coincidence with a line of the graduated arc and the time was noted at which the pendulum was bisected by it at the extremity of its oscillation. The arc was so placed that its zero was 1′ or 2′ away from the vertical, so as to permit the observation to be made both to the right and the left.

The Geneva observations of arc were plotted on a curve for each experiment. Then values of the arc were read off at six equal intervals between every two sets of pendulum-transits. These values were squared, and the mean square was obtained by Mr. Weddle's rule—

$$\int_0^{6h} u_x \, . \, dx = \frac{3h}{10} \left\{ u_0 + u_2 + u_4 + u_6 + 5\,(u_1 + u_5) + 6\,u_3 \right\}.$$

To obtain the correction for arc at Paris, Berlin, and Kew, the first step was to tabulate the times of decrement from a fixed value of the arc to each of the others for all cases in which there were good observations both to the right and to the left. The following tables show—first, the minute and second at which the pendulum was observed to reach each amplitude, and, second, the differences of the times from those of reaching the arc of 1° 10′ on each side of the vertical. A colon signifies that the observation to which it is attached was noted as poor at the time. Brackets inclose numbers derived from observations made only to the right or only to the left, in the manner described below. In the second table a star shows that the time of reaching 1° 10′ was not observed, but was deduced from the time of reaching some other arc, the observation of which is therefore omitted and a star put in its place.

Table showing the minutes and seconds of the times of reaching the different half-amplitudes.

PARIS.

HEAVY END UP.

	Jan. 26.	Jan. 28.	Jan. 29.	Jan. 29.	Feb. 2.	Feb. 4.	Feb. 9.	Feb. 14.	Feb. 21.	Feb. 22.
° ′	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.
2 20	......	......	......	......	......	......	......	......	6 17	......
10	......	......	......	......	......	......	......	......	......	......
00	......	......	......	......	......	......	......	......	......	......
1 50	......	27 21:	......	......	......	39 53	......	59 32	......	......
40	......	......	......	......	......	......	......	......	13 29	......
30	......	......	......	56 20	......	......	......	......	......	......
20	[42 23]	34 36	......	59 13	[51 35]	47 20	25 10	6 56	18 51	52 24
10	46 4	38 7	......	62 42	55 25	50 56	29 2	10 27	22 27	55 59
00	......	......	......	......	......	......	......	......	......	......
0 50	55 39	......	......	72 41	64 38	60 49	38 40	......	32 34	......
40	62 54	......	......	79 32	71 44	67 52	45 38	27 12	39 30	72 20
30	......	......	......	......	......	......	......	37 44:	......	......

HEAVY END DOWN.

	Jan. 26.	Jan. 28.	Feb. 2.	Feb. 2.	Feb. 3.	Feb. 4.	Feb. 9.	Feb. 14.	Feb. 21.	Feb. 22.
° ′	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.
2 20	......	......	......	......	......	......	......	......	......	......
10	......	32 25:	......	......	......	......	......	......	15 31	......
00	......	......	......	......	......	......	......	......	......	......
1 50	30 20	39 56:	32 7	53 48	......	25 53	......	......	23 32	52 36
40	35 1:	44 37	36 48	58 28	......	30 39	51 39	......	28 23	57 33
30	......	......	......	......	25 42:	......	......	......	......	......
20	47 9	56 55:	[48 51]	70 17	32 6	42 6	63 47	44 47	40 45	69 25
10	55 58	......	......	77 52	40 0	49 25	72 3	......	49 3	78 16:
00	......	......	......	......	48 48	......	......	62 57	58 54	......
0 50	77 17	85 52	......	99 00	59 46	69 6	94 41	75 15	71 37	101 2
40	91 28	101 49	......	115 13	74 15	82 29	110 49:	91 47	87 7:	117 20
30	......	......	......	......	94 2	......	132 8	......	109 21	......

Table showing the minutes and seconds of the times of reaching the different half-amplitudes—Continued

BERLIN.

HEAVY END UP.

° ′	Apr. 20. m. s.	Apr. 24. m. s.	Apr. 25. m. s.	Apr. 26. m. s.	Apr. 28. m. s.	Apr. 29. m. s.	Apr. 30. m. s.	May 2. m. s.	June 1 m. s.	June 3. m. s.	June 3. m. s.	June 4. m. s.	June 5. m. s.	June 5. m. s.
2 20	35 38	....	36 58	....	....	....	53 55	....	....	....	....	....	....	....
10	....	....	....	....	....	....	....	....	....	....	....	....	....	....
00	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1 50	....	....	....	....	....	....	....	....	....	....	....	....	....	....
40	42 47	....	43 52	....	....	....	60 51	....	....	....	....	....	....	....
30	....	....	....	....	....	....	....	....	....	....	....	....	....	....
20	48 8	48 00	49 27	....	34 41	57 57	66 10	17 17	....	....	....	....	....	....
10	51 46	[51 38]	53 00	[36 32]	38 17:	[61 35]	[69 41]	20 55	25 55	40 36	11 23	2 29	58 43	30 44
00	....	....	....	....	....	....	....	....	....	....	....	....	....	....
0 50	61 40	61 19	....	46 11	48 00	71 16	79 15	30 15	....	....	....	....	....	....
40	78 35	68 26	69 41	53 23	....	....	85 50	36 50	....	....	....	....	....	....
30	88 42	....	79 36	....	....	....	....	....	[52 19]	67 2	[37 4]	[29 40]	[85 40]	[57 29]

HEAVY END DOWN.

° ′	Apr. 19. m. s.	Apr. 20. m. s.	Apr. 24. m. s.	Apr. 25. m. s.	Apr. 26. m. s.	Apr. 28. m. s.	Apr. 29. m. s.	Apr. 30. m. s.	May 2. m. s.	May 4. m. s.	June 1. m. s.	June 3. m. s.	June 4. m. s.	June 5. m. s.
2 20	49 5	....	51 57	....	18 13	....	58 00	42 3	2 88	....	....	....	....	....
10	52 18	42 51	....	....	....	....	61 12	45 15	5 18	....	....	....	....	....
00	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1 50	....	50 36	62 48	56 42	....	0 29	68 58	53 7	13 28	....	....	....	....	....
40	....	....	67 85	....	33 50	5 16	73 50	57 40	18 11	....	....	....	....	....
30	....	....	....	....	....	....	....	....	....	....	....	....	....	....
20	77 18	68 18	79 32	73 43	46 18	17 34	86 6	70 0	....	....	....	....	....	....
10	[84 42]	75 41	87 39	81 34	53 52	25 31	[93 55]	77 59	38 17	27 35	4 45	15 16	48 24	43 15
1 00	95 11	....	....	....	....	....	104 24	....	....	....	....	....	....	....
50	107 23	97 56	110 3	103 16	75 30	47 24	116 30	99 55	....	....	....	....	....	....
40	....	113 25	124 30	119 40	....	64 11	131 47	115 37	75 40	....	....	....	....	....
30	146 12	135 43	146 34	....	113 10	86 27	156 2	....	97 20	86 26	64 22	75 28	107 22	102 13

KEW.

HEAVY END UP.

° ′	July 1. m. s.	July 2. m. s.	July 2. m. s.	July 3. m. s.	July 3. m. s.	July 4. m. s.	July 4. m. s.	July 4. m. s.	July 4. m. s.	July 7. m. s.
2 40	....	5 00	....	....	....	....	....	....	....	....
30	....	6 10:	....	....	....	....	....	....	....	....
20	0 51	7 27:	22 51:	33 18	35 57	[42 54]	32 21	2 16	59 37	16 54
10	....	8 57:	....	....	....	....	....	....	....	....
00	....	10 28	....	....	....	....	....	....	....	....
1 50	....	....	....	....	....	....	....	....	....	....
40	8 00	....	29 55	40 25	43 8	49 54	39 28	9 30	6 48	26 0
30	....	17 4	....	....	....	....	....	....	....	....
20	13 22	....	35 25	45 57	48 37	55 30	44 50	15 00	12 13	31 38
10	16 58	23 50	39 00	....	52 2	59 5	48 25	18 20	15 51:	....
00	....	28 10:	....	....	....	....	....	....	....	....
0 50	27 2	33 15:	48 47	59 7	61 54:	68 47	58 9	28 9	25 26	44 43
40	....	40 33	55 38:	....	60 1	75 55	65 4	....	....	51 24
30	....	50 29	....	....	....	....	....	....	....	....
20	....	65 2	....	....	....	....	....	....	....	....

Table showing the minutes and seconds of the times of reaching the different half-amplitudes—Continued.

KEW—Continued.

HEAVY END UP—Continued.

	July 7.	July 7.	July 7.	July 8.	July 8.	July 9.	July 9.	July 9.	July 10.	July 10.
° ′	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*
2 40	......	......	......	......	......	......	......	......	......	......
30	......	......	......	......	......	......	......	......	......	......
20	37 30	27 7	19 43	18 22	9 43	11 35	8 35	13 6	24 52	32 46
10	......	......	......	......	......	......	9 57	......	......	......
00	......	......	......	......	......	......	11 33	......	......	......
1 50	......	......	......	......	......	......	......	......	......	......
40	44 38	34 21	......	25 38	16 53	18 43	......	20 7	31 56	39 56
30	......	......	......	......	......	......	......	......	......	......
20	50 13	39 55	32 31	......	22 22	......	......	......	37 23	45 28
10	53 56	43 36	35 48	34 48	......	27 49	......	28 58	40 58	48 58
00	......	......	......	......	......	......	......	......	......	......
0 50	63 41	53 30	46 1	......	35 30	37 57	......	38 35	50 43	58 47:
40	70 27	60 13	52 56	51 38	42 25	......	......	45 30	......	65 45
30	......	......	......	......	......	......	......	......	......	......
20	......	......	......	......	......	......	......	......	......	......

HEAVY END DOWN.

	July 1.	July 2.	July 3.	July 4.	July 4.	July 7.	July 7.	July 8.	July 9.	July 10.
° ′	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*
2 40	......	......	......	......	......	......	......	......	......	......
30	......	......	......	......	......	......	......	......	......	......
20	......	......	......	......	......	......	......	......	......	......
10	[18 24]	39 31	49 2	44 1	5 46	21 6	28 1	24 41	13 22	19 11
00	......	......	......	......	......	......	......	......	......	......
1 50	[26 24]	47 33	56 47	......	13 32	......	36 1	32 46	21 25	27 6
40	[31 13]	52 33	......	56 47	18 31	......	......	37 43	26 15	......
30	......	......	......	......	......	......	......	......	......	......
20	44 19:	64 42	74 22	69 8	31 2	46 50	53 37	50 12	38 57	......
10	[51 21]	72 40	82 8	77 18	39 0	55 5	62 5	58 36	......	52 36
00	......	......	......	......	......	......	......	......	......	......
0 50	[72 50]	94 56:	104 27	98 38	60 35	......	84 38	70 57	69 35	74 49
40	88 41	109 55	120 2	114 45	77 40	93 46	101 19	96 44	85 59	91 6
30	......	......	......	......	......	......	......	......	......	......
20	......	......	174 47	......	......	......	......	......	......	......

Table showing the time of decrement of the arc from 1° 10′.

HEAVY END UP.

PARIS.

	2° 20′.	2° 10′.	1° 50′.	1° 40′.	1° 20′.	0° 50′.	0° 40′.
	m. s.	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*
Jan. 26	......	......	......	......	[− 3 41]	+ 9 35	+16 50
28	......	......	−10 46:	......	− 3 31	......	......
29	......	......	......	......	− 3 29	+ 9 59	+16 50
Feb. 2	......	......	......	......	[− 3 50]	+ 9 13	+16 19
4	......	......	−11 3	......	− 3 36	+ 9 53	+16 56
9	......	......	......	......	− 3 52	+ 9 38	+16 36
14	......	......	−10 55	......	− 3 31	......	+16 45
21	−16 10	......	......	− 8 58	− 3 36	+10 7	+17 3
22	......	......	......	......	− 3 35	......	+16 21
Means...	−16 10	......	−10 59	− 8 58	− 3 38	+ 9 52	+16 45

Table showing the time of decrement of the arc from 1° 10′—Continued.

HEAVY END UP—Continued.

BERLIN.

	2° 20′.	2° 10′.	1° 50′.	1° 40′.	1° 20′.	0° 50′.	0° 40′.
	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.
Apr. 20	−16 8	....	....	− 8 59	− 3 38	+ 9 54	+16 55
24	....	....	....	....	− 3 38	+ 9 41	+16 48
25	−16 2	....	....	− 9 8	− 3 33	....	+16 41
26	....	....	....	....	....	+ 9 39	+16 41
28	....	....	....	....	− 3 36	+ 9 43	....
29	....	....	....	....	− 3 38	+ 9 41	....
30	−15 46	....	....	− 8 50	− 3 31	+ 9 34	+16 9
May 2	....	....	....	....	− 3 38	+ 9 20	+15 55
Means...	−15 59	....	....	− 8 59	− 3 36	+ 9 39	+16 32

KEW.

	2° 20′.	2° 10′.	1° 50′.	1° 40′.	1° 20′.	0° 50′.	0° 40′.
	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.
July 1	−16 7	....	....	− 8 58	− 3 36	+10 4	....
2	−16 23:	−14 53:	....	....	....	+ 9 25:	+16 43
2	−16 9:	....	....	− 9 5	− 3 35	+ 9 47	+16 38:
3	−16 13	....	....	− 9 6	*	+10 24	....
3	−16 5	....	....	− 8 54	− 3 25	+ 9 52:	+16 59
4	[−16 11]	....	....	− 9 11	− 3 35	+ 9 42	+16 50
4	−16 4	....	....	− 8 57	− 3 35	+ 9 44	+16 39
4	−16 13	....	....	− 8 59	− 3 29	+ 9 40	....
4	−16 20	....	....	− 9 3	− 3 38	+ 9 35	....
7	−16 18	....	....	− 9 12	*	+ 9 55	+16 12
7	−16 26	....	....	− 9 18	− 3 43	+ 9 45	+16 46
7	−16 29	....	....	− 9 15	− 3 41	+ 9 54	+16 37
7	−16 5	....	....	....	− 3 17	+10 13	+16 8
8	−16 26	....	....	− 9 10	....	....	+16 50
8	−16 13	....	....	− 9 3	*	+ 9 34	+16 29
9	−16 14	....	....	− 9 6	....	+10 8	....
9	*	−14 50	....	....	....	....	....
9	−15 52	....	....	− 8 51	....	+ 9 37	+16 32
10	−16 6	....	....	− 9 2	− 3 35	+10 45	....
10	−16 12	....	....	− 9 2	− 3 30	+ 9 49	+16 47
Means...	−16 14	−14 51	....	− 9 5	− 3 33	+ 9 54	+16 38

HEAVY END DOWN.

PARIS.

	2° 20′.	2° 10′.	1° 50′.	1° 40′.	1° 20′.	0° 50′.	0° 40′.
	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.
Jan. 26	....	....	−25 38	−20 57:	− 8 49	+21 19	+35 30
28	....	−32 39:	−25 8:	−20 27:	*	+20 43:	+36 45
Feb. 2	....	....	−24 4	−19 24	− 7 35	+21 8	+37 21
3	....	....	....	....	− 7 54	+19 46	+35 15
4	....	....	−23 35	−18 46	− 7 19	+19 41	+33 4
9	....	....	....	−20 24	− 8 16	+22 38	+38 46:
14	....	....	....	....	*	+22 19	+38 51
21	....	−33 32	−25 31	−20 40	− 8 18	+22 34	+38 4:
22	....	....	−25 40	−20 43	− 8 51:	+22 46	+39 4
Means...	....	−33 1	−24 55	−20 10	− 8 9	+21 26	+36 51

Table showing the time of decrement of the arc from 1° 10′—Continued.

HEAVY END DOWN—Continued.

BERLIN.

	2° 20′.	2° 10′.	1° 50′.	1° 40′.	1° 20′.	0° 50′.	0° 40′.
	m. s.	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*
Apr. 19	−35 37	−32 24	....	....	− 7 24	+22 41	....
20	....	−32 50	−25 05	....	− 7 23	+22 15	+37 44
24	−35 42	....	−24 51	−20 04	− 8 7	+22 24	+36 51
25	....	....	−24 52	....	− 7 51	+21 42	+38 06
26	−35 39	....	....	−20 02	− 7 34	+21 38	....
28	....	....	−25 02	−20 15	− 7 57	+21 53	+38 40
29	−35 55	−32 43	−24 57	−20 05	− 7 49	+22 35	+37 52
30	−35 56	−32 44	−24 52	−20 19	− 7 59	+21 56	+37 38
May 2	−35 39	−32 59	−24 49	−20 06	....	....	+37 23
Means...	−35 45	−32 44	−24 58	−20 9	− 7 46	+22 8	+37 45

KEW.

	2° 20′.	2° 10′.	1° 50′.	1° 40′.	1° 20′.	0° 50′.	0° 40′.
	m. s.	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*	*m. s.*
July 2	....	−33 9	−25 07	−20 07	− 7 58	+22 16	+37 15
3	....	−33 6	−25 21	....	− 8 06	+22 19	+37 54
4	....	−33 17	....	−20 31	− 8 10	+21 20	+37 27
4	....	−33 14	−25 33	−20 29	− 7 58	+21 35	+38 40
7	....	−33 59		....	− 8 15	....	+38 41
7	....	−34 4	−26 4	....	− 8 26	+22 33	+39 14
8	....	−33 55	−25 50	−20 53	− 8 24	+22 21	+38 8
9	....	−33 44	−25 41	−20 51	*	+22 29	+38 53
10	....	−33 25	−25 30	....	....	+22 13	+38 30
Means...	....	−33 31	−25 35	−20 36	− 8 09	+22 07	+38 16

The foregoing tables show the amount of discrepancy between the observations of different days. The point of the pendulum is distant 113½ cm. from the knife-edge, so that one minute of arc measures ⅓ of a millimeter. The reading-telescope was placed at a distance of about 3 meters. It may, therefore, be supposed that a single observation of the half-amplitude would be in error by something like ¼ of a minute. The following table shows how much error this would produce in the noted time of attaining the different amplitudes:

Half amplitude.	Time of decrement of ¼. Heavy end up.	Heavy end down.
° ′	*s.*	*s.*
2 10	2	5
1 50	3	7
1 40	3	8
1 20	5	11
1 10	6	13
50	9	21
40	12	27

It will be seen that the observed discrepancies are several times as large as these values, and cannot therefore well be attributed to errors of observation. The daily discrepancies are, however, less than 7 times the numbers just given, that is less than 1¾ minutes. Such errors would produce

an error in the correction for arc proportional to the arc itself and amounting to only 2 millionths for $\Phi = 2^{\circ}$. It has, therefore, been judged proper to find one function to express the relation between the amplitude and the rate of decrement, and to apply this to all the observations at ordinary pressures and temperatures for the purpose of finding the correction for arc.

The pendulum being symmetrical in form in reference to its two knife-edges, the air resists its motion with the same force whichever end is up. Consequently, the rate of decrement of the arc (produced by this cause) is in the two positions inversely proportional to the moments of inertia. But it is the property of the reversible pendulum that the moments of inertia about its two knife-edges are proportional to the distances of the center of mass from those knife-edges. These distances are in our pendulum very nearly in the ratio of 3 to 7. Hence, the times of decrement of the arc (so far as it is the effect of the air) must be in the ratio of 7 with heavy end down to 3 with heavy end up. The same would be true for any proper effect of friction on the knife-edges. But the decrement of the amplitude is no doubt partly caused by the energy of motion of the pendulum itself. For example, the pendulum sets its support in vibration and this vibration is resisted by internal friction, thus exhausting the energy. Such a decrement of the arc will be more nearly equal with heavy end up and with heavy end down, or it may even be greater with heavy end down. In point of fact it will be seen that the times of decrement are a little more nearly equal than if they were in the ratio of the distances of the knife-edges from the center of mass. This is shown by the following table:

STATION, PARIS.

Decrement.	Time, heavy end down.	Calculated time, heavy end up.	Observed time, heavy end up.	O – C
° ′ ° ′	*m.*	*m.*	*m.*	*m.*
1 40 to 1 20	12.0	5.2	5.4	+0.2
1 20 1 10	8.9	3.9	3.6	–0.3
1 10 50	21.4	9.3	9.9	+0.6
50 40	15.4	6.7	6.9	+0.2
1 40 to 40	57.7	25.2	25.8	+0.6

STATION, BERLIN.

Decrement.	Time, heavy end down.	Calculated time, heavy end up.	Observed time, heavy end up.	O – C
° ′ ° ′	*m.*	*m.*	*m.*	*m.*
1 40 to 1 20	12.4	5.4	5.5	+0.1
1 20 1 10	7.8	3.4	3.6	+0.2
1 10 50	22.1	9.6	9.6	0.0
50 40	15.6	6.8	6.9	+0.1
1 40 to 40	57.9	25.2	25.6	+0.4

STATION, KEW.

Decrement.	Time, heavy end down.	Calculated time, heavy end up.	Observed time, heavy end up.	O – C
° ′ ° ′	*m.*	*m.*	*m.*	*m.*
1 40 to 1 20	12.5	5.5	5.5	0.0
1 20 1 10	8.1	3.5	3.6	+0.1
1 10 50	22.1	9.6	9.8	+0.2
50 40	16.1	7.0	6.9	–0.1
1 40 to 40	58.8	25.6	25.8	+0.2

These numbers, however, show that for the purpose of calculating the correction for arc it will be quite sufficient to assume that the times of decrement are in the ratios of the moments of inertia. In order to obtain the law of decrement, therefore, the times with heavy end up and with heavy

end down have been added together; and the means have then been taken for all three stations (Paris, Berlin, and Kew). We thus obtain

Half amplitude.	Sum of times.
′	s.
130	−2880
110	−2187
100	−1779
80	− 706
70	0
50	+1927
40	+3304

The time for 140′ has been neglected as not having been generally observed with heavy end down.

To satisfy these values a form of equation has been assumed which has been copied from Professor Benjamin Peirce's *Analytic Mechanics*, and which is Coulomb's equation with a constant term added. It is—

$$D_t\,\Phi = -a - b\,\Phi - c\,\Phi^2\,.$$

The integral of this equation is

$$\Phi = \sqrt{\frac{a}{c} - \frac{1}{4}\frac{b^2}{c^2}}\,\cot\left\{c\sqrt{\frac{a}{c} - \frac{1}{4}\frac{b^2}{c^2}}(t - t_0)\right\} - \frac{1}{2}\frac{b}{c}\,.$$

The values of Φ for the different values of t, as given in the table above, are sufficiently satisfied by putting (for t in seconds of time and Φ in minutes of arc)

$$a = 1547 \times 10$$
$$b = 6418 \times 10^{-8}$$
$$c = 1421 \times 10$$

The errors are shown in the following table:

Sum of times.	Obs. Φ.	Calc. Φ.	(O—C) Φ.
s.	′	′	′
−3191	140	138.82	+1.18
−2880	130	130.03	−0.03
−2187	110	110.33	−0.33
−1779	100	100.00	−0.00
− 706	80	79.97	+0.03
0	70	70.03	−0.03
+1927	50	49.98	+0.02
+3304	40	39.99	+0.01

By least squares, better values of the constants could be obtained; but these are evidently sufficient for our purpose.

The law of decrement of the amplitude having been made out, it was requisite to apply it to the observations. The constant t_0, being different for each experiment, had first to be determined. In doing this, it was desirable to use observations in which the arc had only been noted on the right or on the left. For this purpose it was necessary to calculate the inclination of the zero of the metallic arc to the vertical. This was readily determined from the difference of the time of reaching a given division to the right and to the left. The following tables show the results so obtained. The figures in parentheses at the top of the column show the estimated inclination from observations of the pendulum at rest.

UNITED STATES COAST SURVEY—PARIS.—DIMINUTION OF ARC.

Calculation of inclination of zero-point.

ϕ	Jan. 26. Heavy end up. dt	(+2′) $d\phi$	Jan. 26. Heavy end down. dt	(−2′) $d\phi$	Jan. 28. Heavy end down. dt	(+1′)	Jan. 28. Heavy end up. dt	($1\frac{1}{4}$′) $d\phi$	Jan. 29. Heavy end up. dt	(−2′) $d\phi$
′	s.	′	s.	′	s.	′	s.	′	s.	′
140										
130					+10:	+0.5				
120										
110			− 57	−2.0	+11:	+0.4	−30:	−2.5		
100			− 63:	−2.0	+11:	+0.3				
90										
80			−104	−2.4	+ 7:	+0.2	−60	−3.1	−67:	- 3.5
70	+22	+0.9	−132	−2.5			−79	−3.4	−69:	−3.0
60										
50	+57	+1.6			+33?	+0.4				
40	+74	+1.6	−222	−2.0	+13	+0.1				
30										
Means....		+1.5		−2.1		+0.3		−3.3		−3.3

ϕ	Jan. 29. Heavy end up. dt	$d\phi$	Feb. 2. Heavy end up. dt	(+1′) $d\phi$	Feb. 2. Heavy end down. dt	($-1\frac{1}{2}$′) $d\phi$	Feb. 2. Heavy end down. dt	$d\phi$	Feb. 4. Heavy end down. dt	($+\frac{1}{2}$′) $d\phi$
′	s.	′	s.	′	s.	′	s.	′	s.	′
140										
130										
120										
110					−53	−2.0	− 57	−2.1	+17	+0.6
100					−74	−2.3	− 77	−2.4	+ 4:	+0.1
90	− 57	−3.5								
80	− 69	−3.6					−102	−2.3	+ 2:	0.0
70	− 88	−3.8	+19	+0.8			−115	−2.2	−15	−0.3
60										
50	−103	−3.0	+38	+1.0			−176	−2.1	−14	−0.2
40	−172	−3.6	+53	+1.1			−293	−2.7	−11	−0.1
30										
Means....		−3.6		+1.0		−2.2		−2.3		0.0

ϕ	Feb. 4. Heavy end up. dt	(−2′) $d\phi$	Feb. 9. Heavy end down. dt	(−2′) $d\phi$	Feb. 9. Heavy end up. dt	($+\frac{1}{2}$′) $d\phi$	Feb. 14. Heavy end up. dt	(−2′) $d\phi$	Feb. 14. Heavy end down. dt	($+\frac{1}{10}$′) $d\phi$
′	s.	′	s.	′	s.	′	s.	′	s.	′
140										
130										
120										
110	− 36:	−3.0					− 22:	−1.9		
100			− 68	- 2.2						
90										
80	− 51:	−3.1	−116	−2.6	+17	+0.9	− 67	−3.5	+14:	+0.3
70	− 73	−3.1	−146	−2.7	+15:	+0.6	− 86	−3.7		
60									+15	+0.2
50	−116	−3.2	−182	−2.2	+34	+0.9			+23	+0.3
40	−165:	−3.5	−222:	−2.1	+38	+0.8	−144	−3.0	+19	+0.2
30			−298	−2.0			−224:	−3.5		
Means....		−3.2		−2.3		+0.8		−3.4		+0.2

Calculation of inclination of zero-point—Continued.

ϕ	Feb. 21. Heavy end down. dt	$d\phi$	Feb. 21. Heavy end up. dt	(+2′) $d\phi$	Feb. 22. Heavy end up. dt	(−2′) $d\phi$	Feb. 22. Heavy end down. dt	(+1′) $d\phi$
′	s.	′	s.	′	s.	′	s.	′
140			+ 23	+2.9				
130	− 58	−2.8						
120								
110	− 70	−2.6					+17	+0.6
100	− 81	−2.6	+ 34	+2.5			+22	+0.7
90								
80	−109	−2.5	+ 46	+2.4	+ 81	+4.2	+27	+0.6
70	−146	−2.7	+ 55	+2.4	+100	+4.3	+28	+0.5
60	−157	−2.4						
50	−149	[−1.8]	+110	+3.0			+78	+0.9
40	−234	−2.2	+133	+2.8	+202	+4.3	+67	+0.6
30	−328	−2.2						
Means		−2.5		+2.7		+4.3		+0.6

UNITED STATES COAST SURVEY.—PENDULUM AT BERLIN.—DECREMENT OF ARC.—INCLINATION OF ZERO-POINT.

ϕ	HEAVY END UP: NAME BACK.								HEAVY END UP: NAME FORWARD.							
	April 24.		April 26.		April 29.		May 2.		April 20.		April 25.		April 28.		April 30.	
	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$
′	s.	′	s.	′	s.	′	s.	′	s.	′	s.	′	s.	′	s.	′
140									+ 29	+3.5	+ 26	+3.1			+ 23	+2.8
130																
120																
110																
100									70	4.9	37	2.6			52	3.6
90																
80							+12	+0.6	89	4.4	75	3.7	+ 81	+4.0	59	2.9
70							12	0.5	102	4.2	76	3.1				
60																
50	12	+0.3	+15	+0.4	15	+0.4			196	5.1			183	4.8	130	3.4
40							91:	1.8:	204	4.1	153	3.1			202	4.0
30									385	5.7	232	3.4				
Means		0.3		0.4		0.4		0.8		4.5		3.1		4.4		3.3

ϕ	HEAVY END UP: NAME FORWARD—CONTINUED.													
	May 4.		June 1.		June 3.				June 4.		June 5.			
	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$
′	s.	′	s.	′		′	s.	′	s.	′	s.	′	s.	′
140														
130														
120														
110														
100														
90														
80														
70	+57	+2.8	+61	+2.5	+ 83	+3.4	+76	+3.1	+106	+4.3	+92	+3.8	+96	+3.9
60														
50														
40														
30					176	2.6								
Means		2.3		2.5		3.0		3.1		4.3		3.8		3.9

PENDULUM AT BERLIN.—DECREMENT OF ARC.—INCLINATION OF ZERO-POINT—Continued.

ϕ	HEAVY END DOWN: NAME BACK.								HEAVY END DOWN: NAME FORWARD.							
	April 24.		April 26.		April 29.		May 2.		April 19.		April 20.		April 25.		April 28.	
	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$
′	s.	′	s.	′	s.	′	s.	′	s.	′	s.	′	s.	′	s.	′
140	+ 37	+1.9	+ 57	+3.0	+ 55	+2.9	+ 47	+2.5	+ 95	+5.0	......	......	......	......	......	......
130	......	......	......	......	......	......	53	2.5	114	5.3	+ 13	+0.6	......	......	......	......
120	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
110	59	2.1	......	......	85	3.0	79	2.8	......	......	22	0.8	+ 17:	+0.6:	+ 36	+1.3
100	65	2.0	74	2.2	95	2.9	74	2.2	......	......	......	......	......	......	38	1.2
90	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
80	83	1.8	111	2.4	144	3.1	......	......	255	5.5	......	......	22	0.5	62	1.3
70	108	1.9	132	2.3	......	......	117	2.1	......	......	19	0.4	15:	0.3:	52	0.9
60	......	......	......	......	252	3.6	......	......	353	5.1	......	......	......	......	......	......
50	309—	......	256	2.9	......	......	......	......	506	5.7	41	0.5	71	0.8	114	1.3
40	248	2.2	284	2.5	361:	3.1	331	2.9	......	......	125	1.1	......	......	203	1.8
30	343	2.2	420	2.7	714:	4.6:	607	3.9	1038	6.7	246	1.6	......	......	254	1.6
Means	......	2.0	......	2.6	......	3.1	......	2.6	......	5.4	......	0.7	......	0.6	......	1.3

HEAVY END DOWN: NAME FORWARD—CONTINUED.

ϕ	April 20.		May 4.		June 1.		June 3.		June 4.		June 5.	
	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$
′	s.	′	s.	′	s.	′	s.	′	s.	′	s.	′
140	+ 14	+0.7	......	......	......	......	......	......	......	......	......	......
130	26	1.2	......	......	......	......	......	......	......	......	......	......
120	......	......	......	......	......	......	......	......	......	......	......	......
110	41	1.4	......	......	......	......	......	......	......	......	......	......
100	34	1.0	......	......	......	......	......	......	......	......	......	......
90	......	......	......	......	......	......	......	......	......	......	......	......
80	65	1.4	......	......	......	......	......	......	......	......	......	......
70	58	1.0	+ 49	+0.9	+ 56	+1.0	+ 49	+0.9	+ 42	+0.7	+ 61	+1.1
60	......	......	......	......	......	......	......	......	......	......	......	......
50	165	1.9	......	......	......	......	......	......	......	......	......	......
40	104	0.9	......	......	......	......	......	......	......	......	......	......
30	......	......	110	1.1	311	2.0	215	1.4	243	1.6	......	......
Means	......	1.2	......	1.0	......	1.5	......	1.1	......	1.1	......	1.1

SUMMARY OF RESULTS.

INCLINATION OF ZERO AT BERLIN.

1876.	Heavy end up.	Heavy end down.
Name back.	′	′
April 24	+0.3	+2.0
26	0.4	2.6
29	0.4	3.1
May 2	0.8	2.6
Name forward.		
April 19	......	5.4
20	4.5	0.7
25	3.1	0.6
28	4.4	1.3
30	3.3	1.2
May 4	2.3	1.0
June 1	2.5	1.5
3	3.0	......
3	3.1	1.1
4	4.3	1.1
5	3.8	1.1
5	3.9	......
Means.		
Name back	+0.5	+2.6
Name forward, excluding April 19	3.6	1.0

UNITED STATES COAST SURVEY—KEW.—DECREMENT OF ARC.—INCLINATION OF ZERO-POINT.

φ	July 1. dt	Heavy end down. $d\phi$	July 1. dt	Heavy end up. $d\phi$	July 2. dt	Heavy end up. d	July 2. dt	Heavy end down. $d\phi$	July 2. dt	Heavy end up. (+2′) $d\phi$	July 3. dt	Heavy end up. (+2½) $d\phi$
′	s.	′	s.	′	s.	′	s.	′	s.	′	s.	′
140			+16	+2.0	+25	+3.1			+23	+2.9	+19	+2.4
130					+26	+2.9	+26	+1.3				
120					+22	+2.1						
110							+23	+0.9				
100			+27	+2.0			+21:	+0.7	+40	+2.9.	+42	+3.1
90					+42	+2.6						
80			+29	+1.5			+25	+0.6	+50	+2.6	+45	+2.3
70			+68	+3.0	+65	+2.8	+53	+1.0	+64	+2.7		
60					+87	+3.0						
50			+36	+1.0	+66	+1.8			+66	+1.8	+73	+2.0
40	+38	+0.3			+93	+2.0	+44	+0.4	+101:	+2.1		
30					+146	+2.3						
Means		+0.3		+1.9		+2.5		+0.8		+2.5		+2.5

φ	July 3. dt	Heavy end down. (+1.5) $d\phi$	July 3. dt	Heavy end up. (+2.6) $d\phi$	July 4. dt	Heavy end up. $d\phi$	July 4. dt	Heavy end down. (+1) d	July 4. dt	Heavy end up. $d\phi$	July 4. dt	Heavy end up. $d\phi$
′	s.	′	s.	′	s.	′	s.	′	s.	′	s.	′
140			27	+3.4					+24	+3.0	+19	+2.4
130	+20	+1.0					+18	+0.9				
120												
110	+25	+0.9										
100			38	+2.8	+42	+3.1	+18	+0.6	+37	+2.7	+31	+2.2
90												
80	+19	+0.4	44	+2.3	+55	+2.9	+40	+0.9	+59	+3.1	+46	+2.4
70	+29	+0.5	75	+3.2	+65	+2.8	+35	+0.6	+75	+3.2	+58	+2.5
60												
50	+24	+0.3	74:	+2.3	+98	+2.7	+83	+1.0	+74	+2.0	+68	+1.9
40	+60	+0.6	109	+2.3	+115	+2.4	+63	+0.6	+134	+2.8		
30												
Means		+0.6		+2.7		+2.8		+0.8		+2.8		+2.3

φ	July 4. dt	Heavy end down. $d\phi$	July 4. dt	Heavy end up. $d\phi$	July 7. dt	Heavy end up. $d\phi$	July 7. dt	Heavy end down. $d\phi$	July 7. dt	Heavy end up. $d\phi$	July 7. dt	Heavy end up. $d\phi$
′	s.	′	s.	′	s.	′	s.	′	s.	′	s.	′
140			+28	+3.5	+22	+2.9			+15	+1.9	+23	+2.9
130	+17	+0.8					−12	−0.6				
120												
110	+40	+1.5					−15:	[−0.6]				
100	+27	+0.9	+35	+2.5	+29	+2.1	−15:	[−0.5]	+27	+2.0	+34	+2.5
90												
80	+36	+0.8	+59	+3.1	+41	+2.1	−28	−0.6	+38	+2.0	+45	+2.3
70	+63	+1.2	+87	[+3.7]			−41	−0.8	+60	+2.6	+46	+2.0
60												
50	+36	+0.4	+93	+2.5	+70	+1.9			+83	+2.3	+59	+1.6
40	+53	+0.5			+87	+1.8	−100	−0.9	+75	+1.6	+100	+2.1
30												
Means		+0.9		+2.9		+2.2		−0.7		+2.1		+2.2

KEW.—DECREMENT OF ARC.—INCLINATION OF ZERO-POINT—Continued.

Φ	July 7. dt	Heavy end down. $d\phi$	July 7. dt	Heavy end up. $d\phi$	July 8. dt	Heavy end up. $d\phi$	July 8. dt	Heavy end down. $d\phi$	July 8. dt	Heavy end up. $d\phi$	July 9. dt	Heavy end up. $d\phi$
′	s.	′	s.	′	s.	′	s.	′	s.	′	s.	′
140	......	......	+ 20	+2.5	+ 17	+2.1	......	......	+24	+3.0	+15	+1.9
130	− 16	−0.8	......	......	......	......	−13	−0.6	......	......	......	......
120	......	......	......	......	......	......	......	......	......	......	......	......
110	− 19	−0.7	......	......	......	......	−37	−1.4	......	......	......	......
100	......	......	......	......	+ 31	+2.3	−20	−0.6	+27	+2.0	+29	+2.1
90	......	......	......	......	......	......	......	......	......	......	......	......
80	− 23	−0.5	+ 41	+2.1	+ 35:	+1.8	−45	−1.0	+45	+2.3	......	......
70	− 33	−0.6	+ 56	+2.4	+ 53	+2.3	−19	−0.4	......	......	+58	+2.5
60	......	......	......	......	......	......	......	......	......	......	......	......
50	− 80	−1.0	+ 74	+2.0	......	......	−49	−0.6	+73	+2.0	+69	+1.9
40	−138	−1.3	+107	+2.3	+111	+2.3	−92	−0.8	+84	+1.8	......	......
30	......	......	......	......	......	......	......	......	......	......	......	......
Mean	......	−0.8	......	+2.3	......	+2.2	......	−0.8	......	+2.0	......	+2.1

Φ	July 9. dt	Heavy end down. $d\phi$	July 9. dt	Heavy end up. $d\phi$	July 10. dt	Heavy end up. $d\phi$	July 10. dt	Heavy end down. $d\phi$	July 10. dt	Heavy end up. $d\phi$
′	s.	′	s.	′	s.	′	s.	′	s.	′
140	......	......	+ 16	+2.0	+21	+2.6	......	......	+ 21	+2.6
130	− 14	−0.7	......	......	......	......	−19	−0.9	......	......
120	......	......	......	......	......	......	......	......	......	......
110	− 15	−0.6	......	......	......	......	−27	−1.0	......	......
100	− 17	−0.5	+ 33	+2.4	+29	+2.1	−14:	−0.4	+ 36	+2.6
90	......	......	......	......	......	......	......	......	......	......
80	− 36	−0.8	......	......	+47	+2.4	......	......	+ 46	+2.4
70	......	......	+ 48	+2.1	+50	+2.1	−37	−0.7	+ 55	+2.4
60	......	......	......	......	......	......	......	......	......	......
50	−103	−1.2	+ 75	+2.1	+60	+1.6	−94	−1.1	+ 75:	+2.1
40	− 66	−0.6	+105	+2.1	+84:	+1.8	−93	−0.9	+107	+2.3
30	......	......	......	......	......	......	......	......	......	......
Mean	......	−0.7	......	+2.1	......	+2.1	......	−0.8	......	+2.4

	Heavy end up.	Heavy end down.
	′	′
July 1	+1.9	+0.3
2	+2.5	
	+2.5	+0.8
3	+2.5	
	+2.5	+0.6
	+2.7	
4	+2.8	+0.8
	+2.8	
	+2.3	+0.9
	+2.9	
July 7	+2.2	−0.7
	+2.1	
	+2.2	−0.8
	+2.3	
8	+2.2	−0.8
	+2.0	
9	+2.1	−0.7
	+2.1	
10	+2.1	−0.8
	+2.4	
Means.		
First days.	+2.6	+0.7
Last days	+2.2	−0.8

The inclination of the zero-point having thus been ascertained, the time of each observation of amplitude to the right and to the left was corrected for inclination so as to give the time of reaching an arc on each side of the vertical of an integral number of tens of minutes. The means of the results for right and left were then taken, in cases where observations were made on both sides. A table calculated from the formula was then entered, giving $t-t_0$ for every ten minutes of Φ, and from this the value of t_0 was obtained. The following tables show the result. The *hours* are omitted.

UNITED STATES COAST SURVEY—PARIS.—DECREMENT OF ARC.—CALCULATION OF t_0.

ϕ	Jan. 26.—Heavy end up.		t Mean	t_0	Jan. 26.—Heavy end down.		t Mean	t_0	Jan. 28.—Heavy end down.		t Mean	t_0	Jan. 28.—Heavy end up.		t Mean	t_0
	From E.	From W.			From E.	From W.			From E.	From W.			From E.	From W.		
′	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
150	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
140	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
130	...	...	...	...	...	...	...	...	32 23	32 27:	32.4	39.3	...	...	...	...
120	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
110	...	35 17	35.3	8.7	30 17	30 20	30.3	29.2	39 54	39 58:	39.9	38.8	27 22	27 20	27.3	0.7
100	37 35	...	37.6	8.9	35 0	35 3	35.0	29.1	44 36	44 37:	44.6	38.7	...	...	...	...
90	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
80	42 45	...	42.7	8.6	47 15	47 3	47.1	28.8	56 59	56 52:	56.9	38.6	34 34	34 38	34.6	0.5
70	46 11	45 57	46.1	8.4	55 8	54 48	55.0	28.5	64 26:	...	64.4	37.9	38 17	38 8	38.2	0.5
60	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
50	55 38	55 41	55.7	8.3	76 13	78 23r	76.2	27.3	85 48	85 57	85.9	37.0	...	...	...	...
40	63 23r	62 25	62.4	8.0	91 51	92 1	91.9	27.1	101 59	101 40	101.8	37.0	...	...	...	...

ϕ	Jan. 29.—Heavy end up.		t Mean	t_0	Jan. 29.—Heavy end up.		t Mean	t_0	Feb. 2.—Heavy end up.		t Mean	t_0	Feb. 2.—Heavy end down.		t Mean	t_0
	From E.	From W.			From E.	From W.			From E.	From W.			From E.	From W.		
′	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
150	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
140	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
130	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
120	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
110	...	...	...	...	...	...	...	...	...	43 54	43.9	17.3	32 4	32 11	32.1	31.0
100	...	...	...	...	...	...	...	...	45 49	...	45.8	17.1	36 49	36 48	36.8	30.9
90	...	...	...	...	56 20	56 21	56.3	25.1	...	...	...	...	...	...	...	...
80	36 20	36 17	36.3	2.2	59 13	59 14	59.2	25.1	51 27	...	51.5	17.4	...	...	...	...
70	39 48	39 57	39.9	2.2	62 40	62 44	62.7	25.0	54 58	54 53	54.9	17.2	...	...	...	...
60	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
50	...	49 34	49.6	2.2	72 27	[72 56]	72.5	25.1	64 37	64 39	64.6	17.2	...	...	...	...
40	...	...	...	...	79 33	79 31	79.5	25.1	71 42	71 47	71.8	17.4	...	...	...	...

ϕ	Feb. 2.—Heavy end down.		t Mean	t_0	Feb. 4.—Heavy end down.		t Mean	t_0	Feb. 4.—Heavy end up.		t Mean	t_0
	From E.	From W.			From E.	From W.			From E.	From W.		
′	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
150	...	...	...	...	...	...	...	...	...	...	...	...
140	...	...	...	...	...	...	...	...	...	35 9	35.1	13.5
130	...	...	...	...	...	...	...	...	...	...	...	...
120	...	...	...	...	...	...	...	...	...	...	...	...
110	53 46	53 51	53.8	52.7	25 46	26 1	25.9	24.8	39 52	39 55	39.9	13.3
100	58 31	58 26	58.5	52.6	30 35	30 35	30.6	24.7	...	42 0	42.0	13.3
90	...	...	...	...	...	...	...	...	...	...	...	...
80	70 17	70 17	70.3	52.0	42 02	42 10	42.1	23.8	47 13	47 24	47.3	13.2
70	77 48	77 57	77.9	51.4	49 36	49 05	49.3	22.8	50 56	50 57	50.9	13.2
60	...	...	...	...	...	...	...	...	...	...	...	...
50	98 52	99 8	99.0	50.1	69 17	68 55	69.1	20.2	60 49	60 49	60.8	13.4
40	115 45	115 3	115.4	50.6	82 40	82 19	82.5	17.7	67 59	67 46	67.9	13.5

UNITED STATES COAST SURVEY—BERLIN.—DECREMENT OF ARC.—CALCULATION OF t_0.

HEAVY END UP: NAME BACK.

ϕ	Correction for inclination.	April 24. W.	April 24. E.	Mean	t_0	April 26. W.	April 26. E.	Mean	t_0	April 29. W.	April 29. E.	Mean	t_0	May 2. W.	May 2. E.	Mean	t_0
′	s.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
140	2	35 32	....	35.5	13.9	20 35	....	20.6	59.0	45 29	....	45.5	23.9	5 13	....	5.2	43.6
130	2	....	....	......	......	....	....	......	......	....	....	......	......	....	....	......	......
120	......	....	....	......	......	....	....	......	......	....	....	......	......	....	....	......	......
110	3	....	....	......	......	....	....	......	......	....	....	......	......	....	....	......	......
100	4	42 29	....	42.5	13.8	27 34	....	27.6	58.9	....	....	......	......	12 2	....	12.0	43.3
90	......	....	....	......	......	....	....	......	......	....	....	......	......	....	....	......	......
80	5	47 55	48 5r	47.9	13.8	32 56	....	32.9	58.8	57 54	58 0r	57.9	23.8	17 16	17 18	17.3	43.2
70	6	51 37:	....	51.6	13.9	36 33	....	36.6	58.9	61 33:	....	61.5:	23.8	20 55	20 55	20.9	43.2
60	8	....	....	......	......	....	....	......	......	....	....	......	......	....	....	......	......
50	10	61 23	61 15	61.3	13.9	46 14	46 9	46.2	58.8	71 19	71 14:	71.3	23.9	29 47r	30 42	30.7	43.3
40	13	68 27	68 25:	68.4	14.0	53 21	53 25:	53.4	59.0	78 28:	....	78.5:	24.1	36 18r	37 23	37.4	43.0
30	17	....	....	......	......	....	....	......	......	....	....	......	......	....	....	......	......

HEAVY END UP: NAME FORWARD.

ϕ	Correction for inclination.	April 20. W.	April 20. E.	Mean	t_0	April 25. W.	April 25. E.	Mean	t_0	April 28. W.	April 28. E.	Mean	t_0	April 30. W.	April 30. E.	Mean	t_0
′	s.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
140	15	35 39	35 38	35.6	14.0	37 0	36 56	37.0	15.4	22 31	....	22.5	0.9	53 59	53 52	53.9	32.3
130	17	....	....	......	......	....	....	......	......	....	....	......	......	....	....	......	......
120	....	....	....	......	......	....	....	......	......	....	....	......	......	....	....	......	......
110	22	....	....	......	......	....	....	......	......	....	....	......	......	....	....	......	......
100	26	42 38	42 54	42.8	14.1	44 0	43 45	43.9	15.2	29 17	....	29.3	0.6	60 51	60 51	60.8	32.1
90	......	....	....	......	......	....	....	......	......	....	....	......	......	....	....	......	......
80	36	48 0	48 17	48.1	14.0	49 26	49 29	49.5	15.4	34 37	34 46	34.7	0.6	66 16	66 3	66.2	32.1
70	44	51 39	51 53	51.8	14.1	53 6	52 54	53.0	15.3	38 17:	38 18	38.3	0.6	....	69 31	69.5	31.8
60	55	....	....	......	......	....	....	......	......	....	....	......	......	....	....	......	......
50	69	61 11	62 9	61.7	14.3	....	62 47	62.8	15.4	47 36	48 21	48.0	0.6	79 19	79 11	79.2	31.8
40	90	68 23	68 47	68.6	14.2	69 55	69 28	69.7	15.3	54 31:	55 4	54.8	0.4	85 39	86 1	85.8	31.4
30	121	77 31	79 54	78.7	15.1	79 41	79 31	79.6	16.0	....	....	......	......	....	....	......	......

HEAVY END UP: NAME FORWARD—CONTINUED.

ϕ	Correction for inclination.	May 4. W.	May 4. E.	Mean	t_0	June 1. W.	June 1. E.	Mean	t_0	June 3. W.	June 3. E.	Mean	t_0	June 3. W.	June 3. E.	Mean	t_0
′	s.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
70	44	46 45	46 13	46.5	8.8	26 9	25 42	25.9	48.2	40 39	40 34	40.6	2.9	11 29	11 17	11.4	33.7
30	121	....	....	......	....	....	52 19	52.3	48.7	67 35	66 29	67.0	3.4	....	37 4	37.1	33.5

HEAVY END UP: NAME FORWARD—CONTINUED.

ϕ	Correction for inclination.	June 4. W.	June 4. E.	Mean	t_0	June 5. W.	June 5. E.	Mean	t_0	June 5. W.	June 5. E.	Mean	t_0
′	s.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
70	44	2 21	2 37	2.5	24.8	58 41	58 45	58.7	21.0	30 40	30 48	30.7	53.0
30	121	....	29 40	29.7	26.1	....	85 40	85.7	22.1	....	57 29	57.5	53.9

BERLIN.—DECREMENT OF ARC.—CALCULATION OF t_0—Continued.

HEAVY END DOWN: NAME BACK.

φ	Correction for inclination.	April 24. W.	April 24. E.	Mean.	t_0	April 26. W.	April 26. E.	Mean.	t_0	April 29. W	April 29. E.	Mean.	t_0
′	s.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
140	25	52 4	51 51	52.0	2.3	18 9	18 16	18.2	28.5	57 57	58 ,2	58.0	8.3
130	28	55 22	…	55.4	2.3	…	21 17	21.3	28.2	60 57	61 22:	61.1	8.0
120	…	…	…	…	…	…	…	…	…	…	…	…	…
110	37	62 56	62 41	62.8	1.7	…	…	…	…	68 53	69 4 ..	69.0	7.9
100	43	67 46	67 25	67.6	1.7	33 56	33 44	33.8	27.9	73 45	73 54	73.8	7.9
90	…	…	…	…	…	…	…	…	…	…	…	…	…
80	60	79 51	79 14	79.5	1.2	46 22	46 13	46.3	28.0	85 54	86 18	86.1	7.8
70	73	87 58	87 20	87.6	1.1	53 59	53 45	53.9	27.4	…	94 22	94.4	7.9
60	91	…	…	…	…	…	63 42:	63.7:	27.2	103 49	104 49:	104.3	7.8
50	115	109 24	110 43r	109.4	0.5	75 17	75 43	75.5	26.6	116 5:	116 35	116.3	7.4
40	149	124 55	124 5	124.5	59.7	91 24:	91 0:	91.2:	26.4	131 16	132 19:	131.8	7.0
30	201	147 4	146 5	146.6	0.6	113 1	113 19	113.2	27.2	153 26	158 38r	153.4	7.4

HEAVY END DOWN: NAME BACK—CONTINUED. / HEAVY END DOWN: NAME FORWARD.

φ	Correction for inclination.	May 2. W.	May 2. E.	Mean.	t_0	φ	Correction for inclination.	April 19. W.	April 19. E.	Mean	t_0	φ	Correction for inclination.	April 20. W.	April 20. E.	Mean	t_0
′	s.	m. s.	m. s.	m.	m.	′	s.	m. s.	m. s.	m.	m.	′	s.	m. s.	m. s.	m.	m.
140	25	2 40	2 37	2.6	12.9	140	52	49 10	49 1	49.1	59.4	140	10	…	…	…	…
130	28	5 50	5 47	5.8	12.7	130	58	52 19	52 17	52.3	59.2	130	11	42 56	42 47	42.9	49.8
120	…	…	…	…	…	120	…	…	…	…	…	120	…	…	…	…	…
110	37	13 36	13 31	13.6	12.5	110	77	…	…	…	…	110	14	50 39	50 33	50.6	49.5
100	43	18 17	18 5	18.2	12.3	100	89	…	…	…	…	100	16	…	…	…	…
90	…	…	…	…	…	90	…	…	…	…	…	90	…	…	…	…	…
80	60	31 3r	30 16	30.3	12.0	80	125	77 16	77 21	77.3	59.0	80	23	68 0	68 36r	68.0	49.7
70	73	38 32	38 3	38.3	11.8	70	152	…	…	…	…	70	28	76 0	75 23	75.7	49.2
60	91	…	…	…	…	60	188	95 23	95 0	95.2	58.7	60	35	…	…	…	…
50	115	59 24	61 0r	59.4	10.5	50	238	107 8	107 38	107.4	58.5	50	44	98 20	97 33	97.9	49.0
40	149	75 23	75 56:	75.7	10.9	40	310	…	…	…	…	40	57	113 20	113 31	113.4	48.6
30	201	95 38	99 3:	97.3	11.3	30	417	144 30	147 54	146.2	60.2	30	77	134 56	136 28	135.7	49.7

HEAVY END DOWN: NAME FORWARD—CONTINUED.

φ	Correction for inclination.	April 25. W.	April 25. E.	Mean.	t_0	April 28. W.	April 28. E.	Mean.	t_0	April 30. W.	April 30. E.	Mean.	t_0
′	s.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
140	10	45 52	…	45.9	56.2	49 30	…	49.5	59.8	42 6	42 0	42.1	52.4
130	11	48 58	…	49.0	55.9	52 48	…	52.8	59.7	45 13	45 17	45.2	52.1
120	…	…	…	…	…	…	…	…	…	…	…	…	…
110	14	56 48	56 37:	56.7	55.6	60 25	60 33	60.5	59.4	52 58	53 15	53.1	52.0
100	16	61 33	…	61.5	55.6	65 13	65 19	65.3	59.4	57 49	57 51	57.8	51.9
90	…	…	…	…	…	…	…	…	…	…	…	…	…
80	23	73 55	73 31	73.8	55.5	77 26	77 42	77.6	59.3	69 51	70 10	70.0	51.7
70	28	81 45:	81 4:	81.4	54.9	85 33	85 29	85.5	59.0	77 58	78 0	78.0	51.5
60	35	…	…	…	…	…	…	…	…	…	…	…	…
50	44	103 25	103 8	103.3	54.4	107 11	107 37	107.4	58.5	99 16	100 33	99.9	51.0
40	57	120 9:	118 52	119.5	54.7	123 27	124 56	124.2	59.4	115 42	115 32	115.6	50.8
30	77	…	…	…	…	145 39	147 16	146.5	60.5	…	138 35:	138.6:	52.6

BERLIN.—DECREMENT OF ARC.—CALCULATION OF t_0—Continued.

HEAVY END DOWN: NAME FORWARD—CONTINUED.

ϕ	Correction for inclination.	May 4. W.		E.		Mean.	t_0	June 1. W.		E.		Mean.	t_0	June 3. W.		E.		Mean.	t_0
′	s.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.
70	28	27	38	27	31	27.6	1.1	4	45	4	45	4.7	38.2	15	50	15	43	15.8	47.3
30	77	86	13	86	29	86.3	0.3	63	2	65	41	64.4	38.4	74	58	75	59:	75.5	49.5

HEAVY END DOWN: NAME FORWARD—CONTINUED.

ϕ	Correction for inclination.	June 4. W.		E.		Mean.	t_0	June 5. W.		E.		Mean.	t_0
′	s.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.
70	28	48	31	48	17	48.4	21.9	43	12	43	17	43.2	15.7
30	77	106	38	108	7	107.4	21.4	101	43	102	43	102.2	16.2

UNITED STATES COAST SURVEY.—PENDULUM AT KEW.—DECREMENT OF ARC.—CALCULATION OF t_0.

HEAVY END UP: FIRST DAYS.

ϕ	Correction for inclination.	July 1. S.		N.		Mean	t_0	July 2. S.		N.		Mean	t_0	July 2. S.		N.		Mean	t_0	July 3. S.		N.		Mean	t_0
′	s.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m	m.	s.	m.	s.	m.	m.
140	10	0	53	0	49	0.8	39.2	7	25	7	30:	7.5	45.9	22	50	22	53	22.9	1.3	33	19	33	18	33.3	11.7
130	12							8	56	8	58:	8.9	45.8												
120	13							10	30	10	26	10.5	45.8												
110	15																								
100	18	8	5	7	56	8.0	39.3			14	36r			29	53	29	57	29.9	1.2	40	22	40	28	40.4	11.7
90	21							17	4	17	04	17.1	45.9												
80	25	13	33	13	12	13.4	39.3							35	25	35	25	35.4	1.3	46	0	45	55	46.0	11.9
70	30	16	54	17	2	17.0	39.3	23	47	23	52	23.8	46.1	38	58	39	2	39.0	1.3			49	33	49.6	11.9
60	37							28	34r	27	47	27.8	45.8												
50	47	27	31	26	33	27.0	39.6	33	29	33	1	33.3	45.9	49	1	48	33	48.8	1.4	59	18	58	57	59.1	11.7
40	62			33	26	33.4	39.0	40	49	40	18	40.6	46.2	55	50r	55	27	55.4	1.0			66	14	66.2	11.8
30	83							50	39	50	19	50.5	46.9												

HEAVY END UP: FIRST DAYS—CONTINUED.

ϕ	Correction for inclination.	July 3. S.		N.		Mean	t_0	July 4. S.		N.		Mean	t_0	July 4. S.		N.		Mean	t_0	July 4. S.		N.		Mean	t_0
′	s.	m.	s.	m.	s	m.	m.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.
140	10	35	53	36	0	35.9	14.3	42	49	42	56	42.9	21.3	32	19	32	23	32.4	10.8	2	17	2	16	2.3	40.7
130	12																								
120	13																								
110	15			40	56	40.9	14.3			47	48	47.8	21.2			37	15	37.2	10.6						
100	18	43	7	43	9	43.1	14.4	49	55	50	1	50.0	21.3	39	28	39	29	39.3	10.6	9	33	9	28	9.5	40.8
90	21																								
80	25	48	40	48	34	48.6	14.5	55	27	55	32	55.5	21.4	44	45	44	54	44.8	10.7	15	2	14	58	15.0	40.9
70	30	51	55	51	50	51.9	14.2	59	3	59	8	59.1	21.4	48	17	48	32	48.4	10.7	18	30	18	28	18.5	40.8
60	37																								
50	47	61	59:	61	49	61.9	14.5	68	45	68	49	68.8	21.4	58	19	57	59	58.1	10.7	28	22	27	56	28.2	40.8
40	62	69	9	68	54	69.0	14.6	75	59	75	50	75.9	21.5	64	59	65	9	65.1	10.7						
30	83																								

PENDULUM AT KEW.—DECREMENT OF ARC.—CALCULATION OF t_0—Continued.

HEAVY END UP: FIRST DAYS—CONTINUED.

φ	Correction for inclination.	July 4. S.	July 4. N.	Mean	t_0
′	s.	m. s.	m. s.	m.	m.
140	10	59 33	59 41	59.6	38.0
130	12				
120	13				
110	15		64 35	64.6	38.0
100	18	66 49	66 48	66.8	38.1
90	21				
80	25	72 9	72 18	72.2	38.1
70	30	75 38	76 5:	75.6	37.9
60	37				
50	47	85 27	85 26	85.4	38.0
40	62	92 20		92.3	37.9
30	83				

HEAVY END UP: LAST DAYS.

φ	Correction for inclination.	July 7. S.	July 7. N.	Mean	t_0	July 7. S.	July 7. N.	Mean	t_0
′	s.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
140	9	18 52	18 56	18.9	57.3	37 32	37 29	37.5	15.9
130	10								
120	11								
110	13						42 34	42.6	16.0
100	15	26 1	26 0	26.0	57.3	44 40	44 37	44.6	15.9
90	18								
80	21	31 39	31 38	31.6	57.5	50 15	50 11	50.2	16.1
70	26		35 0	35.0	57.3	53 52:	54 0	53.9	16.2
60	32								
50	40	44 48	44 38	44.7	57.3	63 40	63 43	63.7	16.3
40	52	51 33	51 16	51.4	57.0	71 12	70 43	71.0	16.6
30	71								

HEAVY END UP: LAST DAYS—CONTINUED.

φ	Correction for inclination.	July 7. S.	July 7. N.	Mean	t_0	July 7. S.	July 7. N.	Mean	t_0	July 8. S.	July 8. N.	Mean	t_0	July 8. S.	July 8. N.	Mean	t_0
′	s.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
140	9	27 5	27 10	27.1	5.5	19 42	19 44	19.7	58.1	18 23	18 22	18.4	56.8	9 40	9 46	9.7	48.1
130	10																
120	11																
110	13		32 6	32.1	5.5		24 47	24.8	58.2		23 22	23.4	56.8		14 42	14.7	48.1
100	15	34 19	34 23	34.3	5.6					25 38	25 39	25.6	56.9	16 55	16 52	16.9	48.2
90	18																
80	21	39 53	39 56	39.9	5.8	32 32	32 31	32 5	58.4	31 24r	31 17	31.3	57.2	22 21	22 24	22.4	48.3
70	26	43 39	43 33	43.6	5.9	36 16	36 20	36.3	58.6	34 48	34 49	34.8	57.1				
60	32																
50	40	53 41	53 20	53.5	6.1	46 4	45 58	46.0	58.6					35 33	35 26	35.5	48.1
40	52	60 15	60 11	60.2	5.8	52 55	52 58	52.9	58.5	51 34	51 41r	51.6	57.2	42 35	42 15	42.4	48.0
30	71																

HEAVY END UP: LAST DAYS—CONTINUED.

φ	Correction for inclination.	July 9. S.	July 9. N.	Mean	t_0	July 9. S.	July 9. N.	Mean	t_0	July 10. S.	July 10. N.	Mean	t_0	July 10. S.	July 10. N.	Mean	t_0
′	s.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.	m. s.	m. s.	m.	m.
140	9	11 37	11 34	11.6	50.0	13 7	13 5	13.1	51.5	24 51	24 54	24.9	3.3	32 45	32 48	32.8	11.2
130	10																
120	11																
110	13		16 31	16.5	49.9		18 0	18.0	51.4		29 49	29.8	3.2		37 43	37.7	11.1
100	15	18 44	18 43	18.7	50.0	20 6	20 9	20.1	51.4	31 57	31 56	31.9	3.2	39 53	39 59	39.9	11.2
90	18																
80	21		24 15	24.2	50.1					37 21	37 26	37.4	3.3	45 27	45 31	45.5	11.4
70	26	27 46	27 52	27.8	50.1	29 0	28 56	29.0	51.3	40 59	40 57	41.0	3.3	48 57	49 0	49.0	11.3
60	32																
50	40	37 32	37 21	37.4	50.0	38 38	38 33	38.6	51.2	50 53	50 33	50.7	3.3	58 50:	58 45	58.8	11.4
40	52	44 24		44.4	50.0	45 30	45 31	45.5	51.1	57 55r	57 35	57.6	3.2	65 44	65 47	65.8	11.4
30	71																

PENDULUM AT KEW.—DECREMENT OF ARC.—CALCULATION OF t_0—Continued.

HEAVY END DOWN: FIRST DAYS.

φ	Correction for inclination.	July 1.				Mean	t_0	July 2.				Mean	t_0	July 3.				Mean	t_0	July 4.				Mean	t_0
		S.		N.				S.		N.				S.		N.				S.		N.			
′	s.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.
140	6																								
130	7	18	24			18.4	25.3	39	25	39	37	39.5	46.4	48	59	49	5	49.0	55.9	43	59	44	3	44.0	50.9
120	8																								
110	10	26	24			26.4	25.3	47	32	47	35	47.6	46.5	56	45	56	50	56.8	55.7						
100	11	31	13			31.2	25.3	52	34r	52	33	52.5	46.6							56	49	56	45	56.8	50.9
90	13																								
80	15	44	19:			44.3:	26.0	64	45	64	40	64.7	46.4	74	28	74	17	74.4	56.1	69	3	69	13	69.1	50.8
70	19			51	21	51.4	24.9	72	33	72	48	72.7	46.2	82	13	82	4	82.1	55.6	77	20	77	17	77.3	50.8
60	23																								
50	29	72	50			72.8	23.9	95	15r	94	37:	94.6	45.7	104	44	104	10	104.5	55.6	98	26	98	51	98.6	49.7
40	38	89	0	88	22	88.7	23.9	110	11	109	39	109.9	45.1	120	10	119	54	120.0	55.2	114	52	114	39	114.8	50.0
30	51																								

HEAVY END DOWN: FIRST DAYS—CONTINUED.

φ	Correction for inclination.	July 4.				Mean	t_0
		S.		N.			
′	s.	m.	s.	m.	s.	m.	m.
140	6						
130	7	5	45	5	48	5.8	12.7
120	8						
110	10	13	22	13	42	13.5	12.4
100	11	18	29	18	34	18.5	12.6
90	13						
80	15	30	59	31	5	31.0	12.7
70	19	38	47	39	12	39.0	12.5
60	23						
50	29	60	46:	60	24:	60.6	11.7
40	38	77	51	77	28	77.7	12.9
30	51						

HEAVY END DOWN: LAST DAYS.

φ	Correction for inclination.	July 7.				Mean	t_0	July 7.				Mean	t_0
		N.		S.				N.		S.			
′	s.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.
140	7												
130	8	21	10	21	2:	21.1	28.0	27	59	27	59:	28.0	34.9
120	9												
110	11	29	28r	29	21	29.4	28.3	36	3	36	0	36.0	34.9
100	13	34	34r	34	23r								
90	15												
80	18	46	54	46	46	46.8	28.5	53	44	53	31	53.6	35.3
70	21	55	6	55	5	55.1	28.6	62	10	62	1	62.1	35.6
60	27												
50	34			77	51	77.9	29.0	84	32	84	44	84.6	35.7
40	44	93	40	93	52	93.8	29.0	100	54	101	44	101.3	36.5
30	59												

HEAVY END DOWN: LAST DAYS—CONTINUED.

φ	Correction for inclination.	July 8.				Mean	t_0	July 9.				Mean	t_0	July 10.				Mean	t_0
		N.		S.				N.		S.				N.		S.			
′	s.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.	m.	s.	m.	s.	m.	m.
140	7																		
130	8	24	43	24	40	24.7	31.6	13	23	13	21	13.4	20.3	19	9	19	13	19.2	26.1
120	9																		
110	11	32	39	32	54	32.8	31.7	21	29	21	22	21.4	20.3	27	4	27	9	27.1	26.0
100	13	37	46	37	40	37.7	31.8	26	20	26	11	26.3	20.4	32	20r	32	8r		
90	15																		
80	18	50	8	50	17	50.2	31.9	38	57	38	57	38.9	20.6						
70	21	58	48	58	25	58.6	32.1							52	39	52	34	52.6	26.1
60	27																		
50	34	81	7	80	48	81.0	32.1	69	17	69	52	69.6	20.7	74	36	75	2	74.8	25.9
40	44	96	42	96	48	96.7	31.9	86	10	85	48	86.0	21.2	91	4	91	9	91.1	26.3
30	59																		

The colons affixed to observations in the above table indicate those which were considered, at the time of making them, of inferior value; and the rejections have, in almost all cases, been made upon the exclusive authority of the original notes.

It will be seen that the value of t_0, which ought to remain constant for each experiment, frequently undergoes a progressive change. On this account three successive values of the constant have been adopted for each experiment, one from $\Phi = 2^\circ$ to $\Phi = 1\frac{1}{2}^\circ$, a second from $\Phi = 1\frac{1}{2}^\circ$ to $\Phi = 1^\circ$, and a third from $\Phi = 1^\circ$ to $\Phi = \frac{1}{2}^\circ$. Within each of these limits there is in no case any change which could occasion a sensible error in the correction for arc.

The values of t_0 having been obtained, the next step was to get the value of Φ at the mean instant of each set of transits. This was done by subtracting t_0 from the mean time of each set, entering the value of $t - t_0$ in a table, and taking out that of Φ.

The next step was to find the integral $\frac{1}{16}\int \Phi^2\, dt$. The formula, obtained by the integration of the expression for Φ given above, is,

$$\int \Phi^2\, dt = -\frac{1}{c}\,\Phi - \frac{1}{2}\,\frac{b}{c^2}\,\text{log. sin.}\left\{\sqrt{a\,c - \tfrac{1}{4}\,b^2}\,(t - t_0)\right\} + \left(\frac{1}{2}\,\frac{b^2}{c^2} - \frac{a}{c}\right)\left(t - t_0\right)$$

In some of the calculations, these three terms were calculated for the observed values of Φ and $(t - t_0)$. In other cases the integral was taken out of a table constructed for the purpose.

The correction of each interval between the successive sets of transits was separately calculated. The approximate values of the corrections were generally as follows:

Interval.	Correction. Heavy end down.	Correction. Heavy end up.
	s.	s.
From $\Phi = 2^\circ$ to $\Phi = 1\frac{1}{2}^\circ$	−0.053	−0.023
From $\Phi = 1\frac{1}{2}^\circ$ to $\Phi = 1^\circ$	−0.043	−0.018
From $\Phi = 1^\circ$ to $\Phi = 1\frac{1}{2}^\circ$	−0.033	−0.014

All the observations of arc at Hoboken, when the Geneva support was employed, were made on a scale divided into decimal parts of the radius. This scale being freely movable, was carefully placed with its zero exactly under the point of the pendulum, when hanging free; so that it was not in general found worth while to observe the arc on more than one side, during the observations taken in June, September, and October—but one allowance for position of zero (0.00043 on September 25) being found necessary in these series. In the observations taken in December and in 1878 less care was taken in placing the scale, and the arc was always observed on both sides, except between 0.024 and 0.010 on the left, when it was hidden from view by one of the supports of the lower platform of the pendulum receiver.

The following tables give the observations of arc in detail, followed by the calculation of inclination, made according to the methods before given.

UNITED STATES COAST SURVEY—HOBOKEN, JUNE, 1877.—DECREMENT OF PENDULUM ARC.—FULL PRESSURE.—SOLID SUPPORT.

TIMES OF REACHING DIFFERENT AMPLITUDES.

	HEAVY END UP.										HEAVY END DOWN.									
June	11	14	15	16	17	19	20	22	29	Mean.	11	14	15	16	17	19	20	22	29	Mean.
′	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.
380												54.5								
370												57.4		26.0	52.1	13.3	2.0	29.7	4.7	
360																				
350																				
340																				
330												62.5		31.3	57.2		7.0	34.8	9.7	34.40
320											38.8	64.4			59.0	20.0	8.4	36.2	11.6	36.07
310														34.5	60.6	21.7	10.2	38.1	13.4	37.75
300	13.2			24.9	49.4	13.9			7.9	20.44	41.8	67.5		36.0	62.7	23.4			15.0	39.41
290				26.1		14.7			8.6	21.30		68.9		38.0		24.9		41.2	16.5	40.99
280	14.6	17.6	17 8		50.4	15.4	5.1			21.98	44.8	70.7		39.5	66.0	26.7	15.3	42.8	18.4	42.66
270										(22.98)					68.2		17.8			45.06
260								25.6		23.89								47.3	23.1	47.61
250										(24.88)		77.0	39.2	47.0	72.8	33.8	22.2	50.0	25.6	49.64
240		22.0									54.4	81.1	41.7				25.0	52.3	28.5	52.50
230		28.1	23.1	31.6	55.8	20.6			14.4	27.07	57.3				78.3	39.0	27.1	54.9		54.91
220		24.5	24.5		56.8		11.0	30.0	15.3	28.24		86.2	47.4	54.9	80.9	41.5		58.1		57.81
210	21.6	25.7	26.0		58.3	22.9	12.4	31.2	16.8	29.56	62.5	88.5		58.1		44.7		61.2	36.4	60.74
200	22.7	27.0	27.2	35.4		24.2	13.8	32.6	17.9	30.84	67.3		53.6	60.6	87.0	48.2		64.1	39.4	64.04
190	24.6			36.6	61.1	25.6	15.1	34.1	19.3	31.09	70.1	95.9	56.2	64.8	90.7	50.7		66.9	43.1	67.30
180					62.5	27.1		35.6		33.91	73.7			68.5	94.2					70.96
170		32.2								35.42		103.5						74.9	49.5	74.74
160		34.6	33.8	41.7					24.0	37.34								81.3:		(79.80)
150	31.2	36.3	35.3	43.6	67.8	32.2	21.6	40.5	26.0	39.11				81.5	107.6			83.5	59.5	84.36
140	33.0		37.3		70.1				27.8	41.10	91.6	117.7		86.2	112.0	81.6:		87.7		88.66
130	34.8	40.6	39.5	47.5	72.1	36.0		44.4	29.5	43.05	96.7			90.7	116.4				68.0	93.40
120	37.1	43.5	42.4	49.8	74.1		28.1	46.4	31.2	45.34	101.5	127.2	84.1	95.8	121.2			97.4	73.2	98.36
110		46.3	44.9	52.4		40.4	30.1	49.2	33.9	47.91	110.6	134.7	90.1	102.6	128.2	95.4		104.4	80.9	105.86
100	42.5	49.6		55.5	79.8	43.5	32.7		37.2	51.01	116.6	142.8	96.2	110.2	136.8	103.5		111.2	88.0	113.16
90	45.7	53.9	51.0	59.0	83.2	46.6	36.2	55.5		54.39	125.9	152.2	103.4	117.4	144.2			119.2		121.42
80	50.2	58.9	56.0		87.5															

UNITED STATES COAST SURVEY.—PENDULUM, HOBOKEN, IN VACUUM APPARATUS.—SEPTEMBER AND OCTOBER, 1877.—HEAVY END DOWN.—H. F., OBSERVER.

TIMES OF REACHING THE DIFFERENT AMPLITUDES.

Arc.	Full pressure.			15 inches.		5 inches.	1½ inch.	½ inch.	¼ inch.	Means.	
	30.3 Sept. 27. 8h	30.2 Oct. 5. 13h	30.2 Oct. 5. 14h	Oct. 5. 8h	Oct. 5. 11h	Oct. 1. 8h	Oct. 1. 12h	Sept. 29. 10h	Oct. 3. 9h	m. 30.23	m. 15
	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.
.0370	....	26.5	54.3	54.7	7.5	14½	44½	2	16	26.6	7.5
360	....	27.8	55.6	57.0	9.8	....	53½	16	33½	27.9	9.8
350	46.7	....	....	....	....	23	62½	30½	49	29.3	....
340	48.1	....	....	....	....	27	72	48	71	30.7	....
330	....	....	....	63.2	15.8	32½	81	65	96½	....	15.8
.0320	....	31.1	....	65.3	18.2	37½	90½	86½	121	33.1	18.1
310	52.8	34.3	61.8	67.7	20.6	41½	99	....	144	34.6	20.5
300	53.6	35.6	63.2	70.0	22.9	46½	104	....	168	35.8	22.8
290	54.9	36.8	64.6	72.6	24.8	....	111	127½	191	37.1	25.1
280	....	38.3	65.9	75.3	27.2	55	120	144	218	38.3	27.6
.0270	58.1	40.6	68.2	78.4	30.2	....	133½	162	249	40.6	30.6
260	59.5	....	....	81.3	....	....	144	181	274	42.0	34.0
250	....	43.4	....	83.8	35.2	....	154½	197	302	43.5	35.8
240	63.1	45.3	73.0	....	38.5	....	164	217	330	45.4	38.7
230	67.3	47.8	75.6	91.6	43.9	....	179	245	359	47.9	44.1
.0220	....	51.5	78.5	95.5	48.3	....	....	272	394	51.2	48.3
210	....	....	81.2	99.5	52.4	....	210	298	429	53.6	52.3
200	73.1	54.8	82.5	....	....	....	222	317	461	55.1	....
190	75.3	57.6	85.0	107.8	58.3	117	....	335	489	57.6	59.4
180	77.8	61.0	88.2	113.0	65.1	....	244	362	527	60.6	65.4
.0170	81.3	67.1	....	....	70.6	136	260	387	573	63.6	70.8
160	85.0	68.3	95.0	123.3	76.5	144	278	416	....	67.5	76.3
150	89.0	71.3	98.5	130.3	80.8	156	297	442	....	71.2	81.9
140	93.8	75.5	103.0	135.7	88.2	167	....	....	....	75.7	88.3
130	98.4	80.1	107.7	143.1	95.6	182	....	516	....	80.4	95.7
.0120	104.4	85.4	113.5	153.1	106.2	199	371	563	....	85.7	106.0
110	106.6	89.5	....	160.2	112.6	215	396	....	....	89.3	112.7
100	113.2	96.8	124.0	167.7	120.3	....	....	....	....	96.3	120.3
90	120.7	104.4	....	179.1	133.4	241½	....	....	....	103.8	132.6
80	....	....	....	....	....	266½	....	....	....	....	....

UNITED STATES COAST SURVEY.—PENDULUM OBSERVATIONS AT DIFFERENT PRESSURES.—DECEMBER, 1877.—HEAVY END UP.—OBSERVATIONS OF ARC.

TIMES OF REACHING THE DIFFERENT AMPLITUDES.

December	23	23	14		12		12	12		16		16		16		16		16		17	
Barometʼr	30.55	30.55	30.25		30.0:		29.9:	29+		29.08		29.08		27.23		27.23		22.4±		15.03	
Right or left.	R.	R.	L.	R.	L.	R.	R.	L.	R.	L.	R.	L.	R.	L.	R.	L.	R.	L.	R.	L.	R.
.039																					
38		12.5									2.8										
37		12.9									3.1									17.8	17.9
36	35.0									2.9	3.6				22.4					18.6	18.7
35	35.6												47.4				8.3				
.034										3.8		47.1		22.9		8.0	8.9				
33													48.4						17.8		
32		15.5																18.5	18.4		
31		16.0										48.8									
30		16.5																			
.029		17.1				41.0									26.8					25.4	25.5:
28	39.7	17.7									8.3			26.6			12.9				
27	40.4	18.5																		27.8	
26	41.2				41.7	42.1	0.6			8.7	9.7		53.2			13.2	14.5			29.0:	29.1
25	42.0	20.1				43.0				9.5		52.7	54.0			14.2	15.5		24.3	30.2	30.3
.024	42.9				43.6	43.9						53.6	54.7			15.0		24.6	25.4	31.7	31.9
23	43.7	21.8				44.9			27.4				55.6				17.5		26.4		33.3
22	44.7	22.8		19.7					28.3				56.7				18.5		27.6		34.8
21		23.8		20.4		47.2					14.6		57.7		34.3		19.7		29.1		
20	47.1	25.0		21.8		48.3	6.7		30.2		15.6		58.9		35.7				30.3		38.1
.019	48.2	26.1				49.5									37.1		22.0		31.7		40.2
18	49.4	27.4		24.1		50.8					18.3				38.4		23.7		33.3		42.3
17	50.7	28.7									19.7				39.9		24.7		35.4		
16	52.2	30.2		27.0		53.5					21.3				41.3						46.8
15	53.8	31.8		28.9		55.2					23.0		66.0		42.9		28.2		39.1		49.6
.014	55.8	33.7				57.3	{17.2?				25.0		67.9		45.3		30.2		41.5		52.2
13	57.7	35.7		32.1		59.4	17.2?				27.0		70.0		47.3		32.6		43.7		55.2
12	59.9	37.7				61.7	20.5				29.4		72.3		49.7		34.8		46.4		58.9
11	62.3	39.8		36.0		64.2	23.5				32.0		75.1		52.8		37.3				62.7
10	64.8	42.4		38.4		66.8	27.2		49.7	29.8	35.1	72.9	78.0±		55.8	35.1	41.1	52.0	52.6		67.1
.009	67.5	45.5	41.4	41.0		70.3	30.9			32.2		75.2		53.7	59.1	37.1			56.3		71.4
08				44.9			36.0?			34.5		78.0±		56.1		40.4				76.6	76.6
07			48.2	48.4										59.5							
.004									79.9												
.003								84.0	90.6												
02					116.0	114.7															

PENDULUM OBSERVATIONS AT DIFFERENT PRESSURES.—DECEMBER, 1877.—HEAVY END UP.—OBSERVATIONS OF ARC—Continued.

December	17		4		19		19		23	22	10		10		8		8		23	22	0	
Baromet'r	. 7.51		7.5±		0.9±		0.75±		0.82	0.81	0.7±		0.7±		0.4±		0.4±		0.46	0.38	0.39	
Right or left.	L.	R.	L.	R.	L.	R.	L.	R.	R.	R.	L.	R.	L.	R.	L.	R.	L.	R.	R.	R.	L.	R.
. 039															38							47. 7
38									36			8			42	41				17		52. 9
37							35	35	40		10	11									58. 8	
36									44		14	16?			54	52					63. 9	
35							45	45	48		20	21			59	58					70. 2	
. 034	56. 1	56. 5					51	50?	52						66	64	36?	37			75. 8	
33	57. 7	58. 1					55	55	57		31	31			72	71	42	42		48	82. 8	
32			13. 1		49	49	60	60			36	36			80	78	49	47		55	87. 8	
31			15. 5?	15. 0	55	55	65	65			41	41	34	34	87	85?	54	52		62	95. 9	
30					61	61	70	70	72		47	46	40	40	93?	93	60	59			103. 2	
. 029		64. 6			66	66	76	76			52	52	45	45	100	100	67	66		77	108. 5	
28	65. 8	66. 4	21. 0		71?	72	82	82			59	58	51	51	107	106	74	73			115. 6	
27	68. 0		23. 1	21. 9		77	88	88			65	65	57	58	114	114	81	80			125. 3	
26	69. 9	70. 3		24. 4	82	83	95	94			71?	71?	63	64	122	121	90	88			134. 5	136. 5
25	72. 0	72. 6	26. 1	26. 8	87	88	101	101			78	78	70	71	129	129					142. 2	143. 1
. 024	74. 1	74. 8	29. 0								85	85	76	78	138	138	106	106	21		150. 2	153. 1
23		77. 4		30. 7		101		114				93		85		148		114	28			160. 5
22		80. 0				107		121				99		92		156		122	36			171. 5
21		82. 3		36. 3		114				26		107		100		165		132	47			
20		85. 1							137	33		115		108		176		141	56			194. 7
. 019		88. 1		41. 3		130			144	42		124		117		186		152	67			203. 5
18		90. 8		45. 2		138		154	152	50		133		126		197			77			214. 3
17		94. 5		48. 3		147		164?	161	59		143		136		211				191		228. 5
16		98. 1				157		175	171	69		154		148		222				206		240. 5
15		102. 4				167		186	183	79		164				234				220		252. 0
. 014		106. 9				177		198	194	91		176		170		247				237		272. 8
13		112. 0				189		210		103		189		182		262				253		
12						201		222				203		195		280						
11		122. 4				215			229					210		301		263				
10		128. 3				229								227		322		282				
. 009		135. 5												245				304				
08		143. 0	94. 4	95. 0														330		365		
07																				388		

UNITED STATES COAST SURVEY.—PENDULUM EXPERIMENTS AT HOBOKEN AT HIGH TEMPERATURES—APRIL AND MAY, 1878.—DIMINUTION OF ARC—Continued.

ARC.	HEAVY END UP.															
Date	April 24.		April 26.	April 24.	April 26.		April 26.		April 30.		April 30.		May 2.		May 2.	
Bar	1.24		2.25	29.91	29.92		29.92		30.03		30.03		29.93		29.93	
Ther	92		100	91	97		98		103		103		95		96	
Right or left.	L.	R.	R.	R.	L.	R.	L.	R.	L.	R.	L.	R.	L.	R.	L.	R.
.034								29.9								
33							29.9	30.6				50.1				
32							30.6				50.1	50.8				51.2
31								31.5			50.8	51.3	7.5	8.0	50.9	
30		59					31.7	32.4			51.4	52.2	8.2	8.6	51.6	51.8
.029	58	65					32.6			7.7		52.7	8.7	9.4		
28	63	70			52.5	53.0			8.0	8.4	52.9	53.4		10.0	52.8	53.3
27	68	76				53.7		34.5	8.7	9.3	53.7		10.3	10.8	53.7	54.1
26	74	82			54.0	54.4	34.7	35.5	9.6	10.0			11.1	11.8	54.5	
25	80	87		14.5	54.7	55.4		36.3	10.4	11.0			12.0	13.5		
.024			5	15.3	55.7			37.3								56.7
23			10	16.7				38.2				58.0				57.6
22			16					39.4		14.0		59.1				58.7
21			21			59.2		40.4		15.3		60.3		16.4		59.8
20			27			60.6		41.6		16.3		61.5		17.6		61.1
.019			33	21.5		61.8				17.6		62.7		18.8		62.2
18				22.8		63.4		44.1		18.9		64.1				
17				23.9		64.9		45.6		20.6				21.8		64.9
16			52	25.8				47.6				67.3		23.3		66.7
15			60			68.1		49.2		24.0		69.2		25.1		68.5
.014			67	29.7		70.0		51.2		25.8		71.2				70.3
13			76			72.2		53.2		28.1		73.3				72.3
12			85	34.2		74.6		55.5		30.4		75.7		31.0		74.6
11				36.7		77.4		58.1		32.8		78.2		33.7		76.9
10				40.1				61.2		35.6		81.0		36.6		79.8
.009				43.6		84.4		64.6		39.1		84.8		40.0		
08				48.1						43.4				43.8		

PENDULUM EXPERIMENTS AT HOBOKEN AT HIGH TEMPERATURES—APRIL AND MAY, 1878.—DIMINUTION OF ARC—Continued.

ARC.	HEAVY END UP—CONTINUED.									HEAVY END DOWN.								
Date....	May 10.		May 10.		May 11.		May 11.		Mean.	May 4.		May 5.		May 6.		May 8.		Mean.
Bar	29.93		29.93		30.00		30.00		29.96	29.83		29.90		30.06		29.88		29.92
Ther ...	92		93		94		94		96.5	97		94		95		95		95.3
Right or left.	L.	R.	L.	R.	L.	R.	L.	R.	R.	L.	R.	L.	R.	L.	R.	L.	R.	R.
.034																		
33											21.9						59.1	
32											23.4					59.4	60.6	
31				57.5				27.0		21.9	24.9		16.9			61.0	62.1	
30				58.3			27.1	27.8		23.1	26.5		18.6			62.4	63.4	
.029			58.3				27.9	28.6	35.20	24.5	28.3	17.2	20.2		8.6	64.1	65.2	29.78
28		14.1	59.0	59.7		44.2	28.7	29.4	35.92	26.2		19.0	22.1			65.7	67.0	31.52
27		15.1	59.7		44.3	44.9		30.1	36.73	28.1		20.7	24.0	8.1	12.0	67.7		33.36
26	15.1		60.7	61.3	44.9	45.9	30.0	31.1	37.59	29.8	34.2	22.5		9.9	14.0			35.28
25	15.9	16.8	61.7	62.2	45.9	46.8	31.0		38.49		36.2	24.4	27.8	11.8			72.6	37.28
.024						47.7			39.44		38.3		30.0				74.7	39.46
23								33.9	40.38		40.6		32.4		21.3		77.0	41.74
22				65.1				34.9	41.42		43.0		34.8		23.3		79.6	44.02
21		20.8		66.3		50.8		36.2	42.55		45.8		37.4		25.8		82.3	46.56
20		22.1		67.6		52.1		37.3	43.78		48.9		40.3		28.6		85.2	49.40
0.19		23.3		68.9		53.4		38.7	45.02		52.1		43.7		31.7		87.9:	52.40
18		24.7		70.3		54.8		40.1	46.42				46.8					55.52
17		26.2		72.0		56.3		41.5	47.95		59.1				38.0		95.7	59.08
16									49.65		62.8		54.4		41.7		99.5	62.72
15		29.5		75.2		59.7		45.1	51.36		67.4		58.6		46.2		103.5	66.86
.014		31.6		77.3		61.7		47.0	53.30		72.1		63.2		51.2		108.0	71.30
13		33.9		79.5		63.9		49.3	55.46		77.5		68.2				113.2	76.32
12		36.1		81.8		66.4		51.9	57.80		83.5						119.3	81.94
11		38.8		84.5		69.0		54.5	60.39								125.5	87.90
10		41.8		87.7		72.0		57.4	63.37								133.6	95.00
.009		45.4		90.9		75.5		61.3	66.92						88.2			103.22
08		49.4				79.6		65.0?			116.0		106.8					

UNITED STATES COAST SURVEY.—PENDULUM OBSERVATIONS OF DECEMBER, 1877.—CALCULATIONS OF POSITION OF ZERO FOR EACH SWING.

Dec.	0		4		8		8		10		10		12		12		14	
ϕ	dt	$d\phi$	dt	$d\phi$	dt	(First.) $d\phi$	dt	(Last.) $d\phi$	dt	(First.) $d\phi$	dt	(Last.) $d\phi$	dt	(First). $d\phi$	dt	(Last.) $d\phi$	dt	$d\phi$
.039																		
38					−1	−.00018												
37									+1	+.00033								
36					−2	33			+2	40								
35					−1	17			+1	20								
.034					−2	29	+1?											
33					−1	14	0	−.00000	0	0								
32					−2	29	−2	40	0	0								
31			−0.5	−.00021	−2	25	−2	29	0	0	0	+.00000						
30					0	0	−1	14	−1	− 17	0	0						
.029					0	0	−1	14	0	0	0	0						
28					−1	13	−1	14	−1	− 14	0	0						
27			−1.2	− 48	0	0	−1	13	0	0	+1	14						
26	+2.0	+.00022			−1	12	−2	25	0	0	+1	17	+0.4	+.00044				
25	+0.9	13	+0.7	+ 29	0	0			0	0	+1	14						
.024	+2.9	29			0	0	0	0	0	0	+2	29	+0.3	+ 33				
......																		
.010																		
09																	−0.4	−.00012
08			+0.6	+ 08														
.007																	+0.2	+ 4
......																		
.003															+6.6	+.00062		
02													−1.3	− 10				
Mean		+.00022		−.00016		−.00014		−.00016		+.00004		+.00010		+.00022		+.00062		−.00004

PENDULUM OBSERVATIONS OF DECEMBER, 1877.—CALCULATIONS OF POSITION OF ZERO FOR EACH SWING—Continued.

Dec.	16		16		16		16		16		17		17		19		19	
	dt	(Pr. 22½). $d\phi$	dt	(Pr. 29, first.) $d\phi$	dt	(Pr. 29, last.) $d\phi$	dt	(Pr. 27, first.) $d\phi$	dt	(Pr. 27, last.) $d\phi$	dt	(Pr. 15.) $d\phi$	dt	(Pr. 7½.) $d\phi$	dt	(First.) $d\phi$	dt	(Last.) $d\phi$
.039																		
38																		
37											+0.1	.00013			0	.00000		
36			+0.7	.00167							+0.1	12						
35															0	0		
.034				167		.00160		.00100	+0.9	.00150			+0.4	.00025	−1	20		
33													+0.4	25	0	0		
32	−0.1	−.00012													0	0	0	.00000
31						120									0	0	0	0
30															0	0	0	0
.029											+0.1	8			0	0	0	0
28								133					+0.6	33	0	0	+1	17
27												8		18	0	0		
26			+1.0	143					+1.3	162	+0.1	8	+0.4	21	−1	14	+1	17
25				129	+1.3	162			+1.3	138	+0.1	8	+0.6	26	0	0	+1	20
.024	+0.8	+ 73			+1.1	150				150	+0.2	13	+0.7	32				
......																		
.010	+0.6	+ 19	+5.3	185	+5.1	179			+6.0	188								
09				194		196	+5.4	170		208								
08				219		200		191		218	0.0	0						
.007								188										
......																		
.003																		
02																		
Mean		+.00026		+.00172		+.00166		+.00156		+.00174		+.00008		+.00026		−.00002		+.00008

ADOPTED MEANS.

Dec. 0	+.00022
4, 8	−.00016
10	+.00006
12	+.00038
14	−.00004
16 (Pr. 22½)	+.00026
16 (Pr. 27, 29)	+.00166
17 (Pr. 15)	+.00008
17 (Pr. 7½)	+.00026
19, 22, 23	.00000

UNITED STATES COAST SURVEY.—HOBOKEN, 1878, APRIL AND MAY.—DIMINUTION OF ARC.—INCLINATION OF ZERO-POINT, RIGHT *minus* LEFT.

[For each reading of arc apparent L the difference is given.]

	HEAVY END UP.																	
	April 24.		April 26.		April 26.		April 30.		April 30.		May 2.		May 2.		May 10.		May 10.	
	dt	Pr. 1.24 $d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$
	m.		*m.*		*m.*		*m.*		*m.*		*m.*		*m.*		*m.*		*m.*	
.0330	.....	.....	.....	.....	0.7	.00100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
20	.....	.....	.....	.....	.....	100	.....	.....	0.7	.00100	.....	.....	.....	.....	.....	.....	.....	.....
10	.....	.....	.....	.....	.....	.....	.....	.....	0.5	100	0.5	.00071	.....	.00050	.....	.....	.....	.....
300	.....	.....	.....	.....	0.7	78	.....	.....	0.8	89	0.4	67	0.2	33	.....	.....	.....	.....
290	7	.00118	.....	.....	.....	71	.....	.....	.....	.....	0.7	87	.....	.....	.....	.....	.....	.00100
.0280	7	133	0.5	.00063	.....	.....	0.4	.00057	0.5	71	.....	.....	0.5	63	.....	.....	0.7	100
70	8	14	.....	.....	.....	.....	0.6	67	.....	63	0.5	63	0.4	50	.....	.....	.....	100
60	8	133	0.4	57	0.8	80	0.4	57	.....	.....	0.7	70	.....	50	.....	.00100	0.6	75
50	7	133	0.7	70	.....	.....	0 6	60	.....	.....	.....	78	.....	.....	0.9	100	0.5	56
40	.....	.....	.....	62	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mean	.....	.00132	.....	.00064	.....	.00086	.....	.00060	.....	.00084	.....	.00072	.....	.00050	.....	.00100	.....	.00084

	HEAVY END UP—CONTINUED.				HEAVY END DOWN.							
	May 11.		May 11.		May 4.		May 5.		May 6.		May 8.	
	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$	dt	$d\phi$
	m.		*m.*		*m.*		*m.*		*m.*		*m.*	
.0330	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.2	.00080
10	.....	.....	.....	.....	3.0	.00200	.....	.....	.....	.....	1.1	73
300	.....	.....	0.7	.00088	3.4	220	.....	.....	.....	.....	1.0	77
290	.....	.....	0.7	88	3.8	227	3.0	.00182	.....	.....	1.1	61
.0280	.....	.....	0.7	88	.....	219	3.1	175	.....	.....	1.3	72
70	0.6	.00086	.....	.....	.....	211	3.3	174	3.9	.00231	.....	61
60	1.0	100	1.1	110	4.4	217	.....	179	4.1	223	.....	.....
50	0.9	100	.....	111	.....	.....	3.4	179	.....	212	.....	.....
40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mean	.....	.00096	.....	.00098	.....	.00216	.....	.00178	.....	.00222	.....	.00070

SUMMARY.

		Heavy end up.	Heavy end down.
April	26	.00064	.....
	26	86	.....
	30	60	.....
	30	84	.....
May	2	72	.....
	2	50	.....
	10	100	.....
	10	84	.....
	11	96	.....
	11	98	.....
	4	.....	.00216
	5	.....	178
	6	.....	222
	8	.....	.....
Means		.00078	.00204

The December observations were corrected for inclination by the proper additions to the time of arcs observed on the right side only. For the observations at high temperatures, the observed times on the right side were taken, and the arcs corrected,

In heavy-end-up observations, all days except the first, by	-0.0004
In heavy-end-down observations, May 4, 5, and 6, by	-0.001
In heavy-end-down observations, May 8, by . .	-0.00035

The differential formula connecting the arc and the time was next found. Only three constants were employed, as has been already stated, the observations not being sufficiently numerous or sufficiently exact to admit of four. The equation, then, is

$$\mathrm{D}_t\phi = -b\varphi - c\varphi^2.$$

$$\text{Hence, } \varphi = \frac{b}{c}\left(\mathfrak{S}^{bt} - 1\right)^{-1},$$

$$\frac{1}{16}\int \varphi^2 \, \mathrm{d}\, t = \frac{b}{16\, c^2}\left\{ b\, t - \text{Nat. log.}\left(\mathfrak{S}^{bt} - 1\right) - \left(\mathfrak{S}^{bt} - 1\right)^{-1} \right\} + \mathrm{C}.$$

$$= \frac{b}{16\, c^2}\left\{ \text{Nat. log.}\left(1 + \frac{c}{b}\varphi\right) - \frac{c}{b}\varphi \right\} + \mathrm{C},$$

$$\text{and } t = \frac{1}{b}\ \text{Nat. log.}\ \left(1 + \frac{b}{c\,\varphi}\right).$$

The constants b and c, for heavy end up, calculated from the observed times of decrement, but not corrected by least squares, are given in the subjoined table.

From the observations of decrement were deduced, first, an equation of the form

$$b + c\,\varphi_{\mathrm{m}} = n,$$

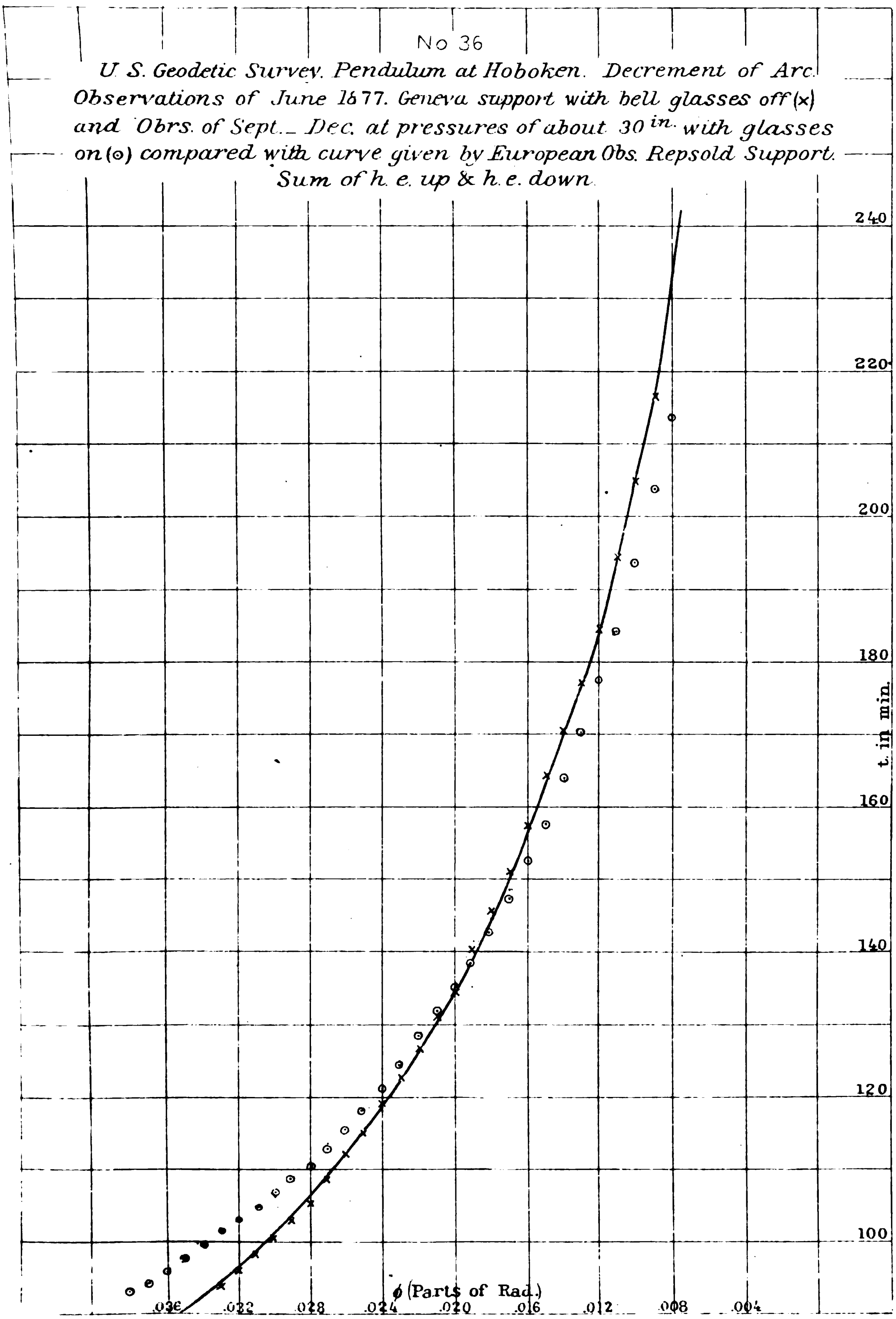
φ_{m} denoting the mean value of φ; and, second, a value of c. As c has been supposed proportional to the density of the air, we find

$$c = 0.03125\ \frac{\sqrt{p}}{\tau}$$

By substituting these values in the equations $b + c\,\varphi_{\mathrm{m}} = n$, we obtain new values of b, called "second reduction" in the table; the "first reduction" having been obtained with the original values of c. These second values answer to the formula

$$b = 0.0013\ \tau^{\frac{3}{4}} + 0.00435\ p^{\frac{1}{2}}\ \tau^{-\frac{1}{2}}.$$

For the observations in which the bell-glasses were on the receiver, these alone being comparable with one another, the values of b, thus calculated, are given in the table, along with the values from the reduction of observations of decrement. Also in illustration No. 36, before alluded to.


No 36
U. S. Geodetic Survey. Pendulum at Hoboken. Decrement of Arc.
Observations of June 1677. Geneva support with bell glasses off (x)
and Obrs. of Sept.–Dec. at pressures of about 30 in. with glasses
on (⊙) compared with curve given by European Obs. Repsold Support.
Sum of h. e. up & h. e. down.
240
220
200
180
160
140
120
100
t. in min.
ϕ (Parts of Rad.)
.036
.032
.028
.024
.020
.016
.012
.008
.004

UNITED STATES COAST SURVEY.—PENDULUM AT HOBOKEN.—DECREMENT OF ARC.

[The constants b and c, as deduced from the observations, compared with values dependent on pressure and temperature of the air.]

	Pressure.	Temp. C.	τ	$\frac{p}{\tau}$	$\frac{\sqrt{p}}{\sqrt[8]{\tau}}$	ϕ_m	$b+c\phi_m$	c	$0.03125\frac{p}{\tau}$	Excess of c.	b, 1st red'n.	b, 2d red'n.	$\left\{\begin{matrix} 0.0013\ \tau^{\frac{3}{4}} \\ +0.00435\frac{\sqrt{p}}{\sqrt[8]{\tau}}\end{matrix}\right\}$	Excess of b.
1877.	*in.*	°												
June	30.12	19.7	1.016	29.65	5.48	.021	0.0364	+0.58	....	......	0.0242	....	....	....
Sept. and Oct.	30.22	18.0	1.010	29.92	5.49	.023	0.0469	+0.91	0.93	—0.02	0.0259	0.0254	0.0252	+.0002
	15.08	18.8	1.013	14.89	3.88	.0205	.0270	.39	.46	— .07	.0189	.0175	.0182	— 7
	4.99	20.5	1.019	4.90	2.23	.023	.0146	.13	.15	— .02	.0117	.0110	.0110	0
	1.50	20.3	1.018	1.48	1.22	.024	.0084	.09	.05	+ .04	.0063	.0073	.0066	+ 7
	0.50	20.5	1.019	0.49	0.71	.0345	.0048	+ .02	.02	.00	.0042	.0044	.0044	0
	0.25	20.6	1.019	0.25	0.50	.027	.0032	— .03	.01	— .04	.0040	.0029	.0035	— 6
December...	29.81	10.5	0.984	30.30	5.47	.0225	0.0470	+1.05	0.95	+ .10	0.0250	.0257	0.0251	+.0006
	27.20	10.4	0.984	27.64	5.23	.018	.0421	0.84	.87	— .03	.0270	.0265	.0240	+ 25
	22.45	10.8	0.985	22.80	4.75	.017	.0327	.57	.71	— .14	.0230	.0206	.0219	— 13
	15.02	10.5	0.984	15.26	3.88	.0185	.0264	.50	.48	+ .02	.0171	.0175	.0182	— 7
	7.46	9.8	0.982	7.60	2.74	.021	.0176	.19	.24	— .05	.0136	.0126	.0132	— 6
	0.75	9.9	0.982	0.76	0.87	.022	.0062	.01	.02	— .01	.0059	.0056	.0051	+ 5
	0.40	10.0	0.983	0.41	0.63	.023	.0046	.01	.01	.00	.0045	.0043	.0040	+ 3
1878. Apr. and May	29.92	35.7	1.072	27.91	5.42	.0186	0.0400	+0.84	0.87	— .03	0.0243	0.0238	0.0249	—.0011

From the calculated b and c we obtain values of t_0, which are given in the following tables.

For the observations of June, 1877, without the bell-glasses, the values of b and c given by the observed decrement of arc, were used unaltered.

UNITED STATES COAST SURVEY.—PENDULUM AT HOBOKEN, JUNE, 1877.—CALCULATION OF t_0.

[Quantities in brackets correspond to observations not on the even thousandth, but on arcs differing a little from those given in the first column.

ϕ	HEAVY END UP.									HEAVY END DOWN.								
	June 11.	June 14.	June 15.	June 16.	June 17.	June 19.	June 20.	June 22.	June 29.	June 11.	June 14.	June 15.	June 16.	June 17.	June 19.	June 20.	June 22.	June 29.
′	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.
.038	......	......	......	......	......	......	......	......	......	[25.4]	50.7r	......	......	......	......	......	......	......
37	......	......	......	......	......	......	......	......	......	......	53.4	[14.7]	21.0	47.1	8.3	57.0	24.7	59.7
36	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
35	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
34	......	......	......	......	......	......	......	......	......	[26.2]	......	......	......	......	......	......	......	......
33	......	......	......	......	......	......	......	......	......	[26.6]	51.9	......	20.7	46.6	[8.0]	56.4	24.2	59.1
32	......	......	......	......	......	......	......	......	......	26.6	52.2	14.5?	......	46.8	7.8	56.2	24.0	59.4
31	......	......	......	......	......	......	......	......	......	26.3	......	......	20.7	46.8	7.9	56.4	24.3	59.6
30	40.3	......	......	52.0	16.5	41.0	......	......	35.0	26.2	51.9	13.7?	20.4	47.1	7.8	......	[24.3]	59.4
29	[39.8]	......	......	52.3	[15.9]	40.9	......	......	34.8	......	51.5	14.3?	20.6	......	7.5	......	23.8	59.1
28	40.0	43.0	43.2	......	15.8	40.8	30.5	......	......	25.5	51.4	......	20.2	46.7	7.6	56.0	23.5	59.1
27	......	......	......	......	......	......	......	......	......	......	......	......	......	46.9	......	56.5	......	......
26	......	......	......	......	......	......	......	49.2	......	......	......	......	......	......	[8.1]	......	23.8	59.6
25	......	......	......	......	......	......	......	......	......	[25.3]	51.3	13.5	21.3	47.1	8.1	56.5	24.3	59.9
24	......	43.6	......	[52.2]	......	......	......	......	[34.9]	26.3	53.0	13.6	[21.8]	......	[8.6]	56.9	24.2	60.4
23	[40.1]	43.6	43.6	52.1	16.3	41.1	......	......	34.9	26.6	[52.9]	......	......	47.6	8.3	56.4	24.2	[60.2]
22	......	43.8	43.8	[52.0]	16.1	......	30.3	49.3	34.6	......	52.9	14.1	21.6	47.6	8.2	......	24.8	[60.0]
21	39.7	43.8	44.1	[52.1]	16.4	41.0	30.5	49.3	34.9	26.3	52.3	......	21.9	......	8.5	......	25.0	60.2
20	39.4	43.7	43.9	52.1	......	40.9	30.5	49.3	34.6	28.0	[53.5]	14.3	21.3	47.7	8.9	......	24.8	60.1
19	39.9	......	43.6	51.9	16.4	40.9	30.4	49.4	34.6	27.5	53.3	13.6	22.2	48.1	8.1	......	24.3	60.5
18	......	......	......	......	16.3	40.9	......	49.4	......	27.6	......	......	22.4	48.1	......	......	[2500]	......
17	......	44.3	......	......	......	......	......	......	......	[27.5]	53.6	......	[22.6]	[48.5]	[22.4]r	......	25.0	59.6
16	......	44.9	44.1	52.0	......	......	......	......	34.3	[28.2]	......	......	......	......	......	......	27.3	......
15	39.6	44.7	43.7	52.0	16.2	40.6	30.0	48.9	34.4	[28.8]	......	......	23.0	49.1	......	......	25.0	61.0
14	39.3	......	43.6	[51.8]	16.4	......	......	......	34.1	28.2	54.3	......	22.8	48.6	18.2r	......	24.3	......
13	38.7	44.5	43.4	51.4	16.0	39.9	......	48.3	33.4	28.0	52.9	[11.8]	22.0	47.7	......	......	......	59.3
12	38.4	44.8	43.7	51.1	15.3	......	29.4	47.7	32.5	26.9	52.6	9.5	21.6	46.6	[15.2]	......	22.8	58.6
11	......	44.8	43.4	50.9	[15.5]	38.9	28.6	47.7	32.4	29.4	53.5	8.9	21.4	47.0	14.2	......	23.2	59.7
10	37.8	44.9	......	50.8	15.1	38.8	28.0	[47.5]	32.5	28.0	54.2	7.6	21.6	48.2	14.9	......	22.6	59.4
09	37.4	45.6	42.7	50.7	14.9	38.3	27.9	47.2	......	29.0	55.3	6.5	20.5	47.3	......	......	22.3	......
.008	37.7	46.4	43.5	[50.5]	15.0	......	......	[50.8]	......	[31.0]	......	......	......	......	......	......	......	......

UNITED STATES COAST SURVEY.—PENDULUM OBSERVATIONS AT HOBOKEN, SEPTEMBER-OCTOBER, 1877.—CALCULATED t_0 FOR EACH SWING.

ϕ	Full pressure.		Pr. 15.			Pr. 5.	Pr. 1.5.	Pr. 0.5.	Pr. 0.25.
	Sept. 27.	Oct. 5.	Oct. 5.	Oct. 5.	Oct. 5.	Oct. 1.	Oct. 1.	Sept. 29.	Oct. 3.
	m.	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*	*m.*
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
.037	......	24.0	−3.8	36.9	84.1	208.5	491.9	1120.0	1715.0
36	......	23.8	4.0	36.4	83.6	......	490.3	1118.7	1715.1
35	6.0	......	......	......	......	208.1	488.8	1117.1	1717.4
34	5.9	......	......	......	......	207.6	487.1	1113.2	1713.4
33	......	......	......	36.2	83.6	206.3	486.2	1109.9	1706.9
32	......	23.4	......	36.3	83.4	205.7	485.1	1102.6	1701.6
31	5.1	23.6	3.9	36.1	83.2	206.2	485.2	......	1698.9
30	5.7	23.7	3.9	36.2	83.3	205.9	489.3	......	1695.4
29	6.0	24.1	3.7:	36.1	83.9	......	491.7	1107.3	1694.0
28	......	24.2	3.4	36.0	84.1	207.5	492.5	1107.4	1689.2
27	6.1	23.6	4.0	35.6	83.8	......	489.1	1106.5	1681.6
26	6.5	......	......	35.6	......	......	489.3	1105.5	1680.8
25	......	24.5	......	36.2	84.8	......	489.8	1108.0	1677.7
24	6.8	24.6	3.1	......	84.8	......	488.0	1107.4	1675.9
23	4.8r	24.3	3.5	35.1	82.8	......	489.2	1099.7	1674.3
22	......	22.9	4.1	34.7	81.9	......	......	1093.8	1668.1
21	......	......	4.3:	34.7	81.8	......	484.5	1090.4	1663.2
20	6.4	24.7	3.0	......	......	......	486.8	1094.9	1662.1
19	7.0	24.7	2.7	34.9	84.4	210.7	......	1101.5	1667.8
18	7.6	24.4	2.8	34.5	82.4	......	495.8	1100.9	1664.8
17	7.4	21.6r	......	......	82.0	205.2	496.7	1103.4	1655.9
16	7.3	24.0r	2.7	34.8	81.6	207.3	496.8	1104.2	......
15	7.2	24.9	2.3	33.8	83.3	206.2	497.1	1109.7	......
14	6.8	25.1	2.4	34.9	82.4	207.0	......	......	......
13	6.9	25.2	2.4	34.7	82.2	204.8	......	1106.2	......
12	6.2r	25.2	2.9	32.5	79.4	202.4	491.2	1098.5	......
11	10.2	27.3	......	34.2	81.8	201.3	493.0	......	......
10	9.9	26.3	−0.9	36.5	83.9	......	......	......	......
09	9.9	26.2	......	36.1	81.8	205.0	......	......	......
.008	......	......	......	......	......	207.6	......	......	......

ϕ	Pr. 30.
	Sept. 25.
	m.
.03473	13.1
3363	13.4
3343	12.7
3173	13.3
2763	11.1
2633	11.4
2533	11.8
2483	11.7
2433	11.2
2263	11.0
2223	10.9
2163	10.3
1983	11.0
1913	11.9
1843	12.6
1733	11.6
1683	12.3
1653	12.4
1543	12.5
1513	12.7
1493	12.5
1363	13.2
1343	13.8
1333	12.7
1243	11.3
1193	12.0
1173	12.3
1033	13.0
0997	14.3
963	15.9
957	15.8
943	16.4
937	15.8
943	15.4
917	16.8
953	13.6
937	13.8
933	14.1
917	14.8
853	15.7
847	15.3
843	15.6
.00847	14.8

ϕ	Pr. 15.
	Sept. 26.
	m.
......	......
......	......
......	......
.0321	61.5
320	61.2
319	60.9
301	61.3
299	61.0
276	59.5
273	59.3
270	59.1
254	59.3
248	59.3
244	60.1
236	58.8
230	59.8
226	60.7
210	59.3
208	58.9
207	57.0
200	60.1
190	60.5
180	60.8
170	60.6
160	58.9
149	58.2
147	58.8
139	59.1
138	59.3
130	59.8
120	59.7
110	59.9
100	60.2
.0090	57.7

UNITED STATES COAST SURVEY.—PENDULUM OBSERVATIONS OF DECEMBER, 1877.—CALCULATIONS OF t_0 FOR EACH SWING.

D = Density of the air compared with one absolute atmosphere at 0° C.

D...	0.964	0.964	0.964		0.964		0.964	0.964		0.964		0.964		0.893		0.893		0.729		0.479		0.245	
Dec	23	23	14		12		12	12		16		16		16		16		16		17		17	
.039																							
38		+ 9.1									+18.8												
37		9.1									18.9									22.1	22.0		
36	−12.5									19.6	18.9				+1.7					22.1	22.0		
35	12.6												−24.4				+16.3						
.034										19.7		23.6		2.2		17.1	16.2					16.6	16.2
33													24.3						+12.9			16.4	16.0
32		9.1																12.9	13.0				
31		9.2										23.6											
30		9.4																					
.029		9.4				−14.5									1.5					22.0	21.9:		15.7
28	12.5	9.5									18.9			2.5			16.2					16.3	15.7
27	12.4	9.5																		21.9		15.9	
26	12.4				12.9	13.3	+28.2			19.9	19.1		24.4			17.5	16.2			21.9:	21.8	15.9	15.5
25	12.4	9.5				13.4				20.1		23.1	24.4			17.4	16.1		13.2	22.1	22.0	15.8	15.2
.024	12.4				13.1	13.4						23.1	24.2			17.5		14.0	13.2	22.0	21.8	15.9	15.2
23	12.3	9.6				13.5			+4.0				24.2				16.0		13.3		21.9		14.8
22	12.3	9.6		+12.7					4.1				24.5				16.0		13.3		22.0		14.6
21		9.7		13.1		13.7					18.9		24.2		1.4		16.0		13.1				14.8
20	12.5	9.6		12.8		13.7	27.9		4.4		19.0		24.3		1.2				13.3		22.2		14.7
.019	12.3	9.8				13.6									1.1		16.2		13.4		22.0		14.5
18	12.2	9.8		13.1		13.6					18.9				1.2		15.9		13.4		22.0		14.9
17	12.0	10.0									19.0				1.2		16.4		13.0				14.4
16	12.0	10.0		13.2		13.3					18.9				1.5						22.1		14.3
15	11.9	10.1		13.0		13.3					18.9		24.1		1.7		16.4		13.3		21.9		13.8
.014	12.0	10.1				13.5	26.6?				18.8		24.1		1.2		16.3		13.1		22.2		13.4
13	11.8	10.2		13.8		13.5	28.7?				18.9		24.1		1.4		16.1		13.4		22.3		12.8
12	11.7	10.5				13.5	27.7				18.8		24.1		1.4		16.3		13.4		22.0		
11	11.4	11.1		14.9		13.3	27.4				18.9		24.2		1.0		16.5				22.0		12.7
10	11.2	11.2		15.2		13.2	26.4		3.9	23.8	18.5	19.3	24.4±		1.0	21.7	15.7	14.2	13.4		21.9		12.8
.009	−10.6	11.4	15.5	15.9		13.4	26.0			24.7		18.3		6.5	1.1	23.1			13.8		22.4		13.3
08				15.8			24.7?			26.2		17.3±		8.1		23.8					22.8		12.5
07			16.9	16.7										9.3									
.004									5.1														
.003								11.9	5.3														
02					4.1	2.8																	

PENDULUM OBSERVATIONS OF DECEMBER, 1877.—CALCULATION OF t_0 FOR EACH SWING—Continued.

D...	0.245		0.025		0.025		0.025	0.025	0.025		0.025		0.013		0.013		0.013	0.013	0.013	
Dec.	4		19		19		23	22	10		10		8		8		23	22	0	
.039													511.4							501.7
38							324.2			352.2			513.1	514.1				538.1		502.2
37			329.5	329.5			324.5		354.5	353.5									502.2	
36							325.0		355.0	353.0?			513.0	515.0					503.1	
35			328.5	328.5			325.5		353.5	352.5			514.3	515.3					503.1	
.034			327.3	328.3?			326.3						513.7	515.7	543.7	542.7			503.9	
33			328.1	328.1			326.1		352.1	352.1			514.3	515.3	544.3	544.3		538.3	503.5	
32	62.5		328.2	328.2	339.2	339.2			352.2	352.2			513.2	515.2	544.2	546.2		538.2	505.4	
31	61.6?	62.1	328.4	328.4	338.4	338.4			352.4	352.4	359.4	359.4	513.2	515.2?	546.2	548.2		538.2	504.3	
30			328.7	328.7	337.7	337.7	326.7		351.7	352.7	358.7	358.7	514.6?	514.6	547.6	548.6			504.4	
.029			328.4	328.4	338.4	338.4			352.4	352.4	359.4	359.4	515.2	515.2	548.2	549.2		538.2	506.7	
28	61.1		328.1	328.1	339.1?	338.1			351.1	352.1	359.1	359.1	516.2	517.2	549.2	550.2			507.6	
27	60.8	62.0	328.3	328.3		339.3			351.3	351.3	359.3	358.3	517.2	517.2	550.2	551.2			505.9	
26		61.4	327.6	328.6	340.6	339.6			351.6?	351.6?	359.6	358.6	517.9	518.9	549.9	551.9			505.4	503.4
25	61.7	61.0	328.1	328.1	342.1	341.1			351.1	351.1	359.1	358.1	519.8	519.8					506.6	505.7
.024	61.0								351.1	351.1	360.1	358.1	520.0	520.0	552.0	552.0	637.0		507.8	504.9
23		61.5		329.3		342.3				350.3		358.3		519.7		553.7	639.7			507.2
22				329.8		343.8				351.8		358.8		522.0		356.0	642.0			506.5
21		60.8				344.8		434.8		351.8		358.8		523.7		556.7	641.7			
20							330.2	433.2		352.2		359.2		523.8		558.8	643.8			505.1
.019		61.3				346.0	332.0	434.0		352.0		359.0		525.7		559.7	644.7			508.2
18		60.5		331.4		347.4	333.4	435.4		352.4		359.4		527.1			647.1			509.8
17		60.6		331.3?		348.3	334.3	436.3		352.3		359.3		526.4				546.4		508.9
16				330.9		348.9	334.9	436.9		351.9		357.9		529.6				545.6		511.1
15				331.3		350.3	334.3	438.3		353.3				532.7				546.7		514.7
.014				331.4		352.4	335.4	438.4		353.4		359.4		535.9				545.9		510.1
13				332.5		353.5		439.5		353.5		360.5		538.2				547.2		
12				334.7		355.7				353.7		361.7		539.0						
11						857.3	343.3					362.3		538.7		576.7				
10						360.2						362.2		540.2		580.2				
.009												363.3				583.4				
08	61.1	60.5														585.4				
07																				
......																				
.004																				
.003																				
02																				

UNITED STATES COAST SURVEY.—HIGH-TEMPERATURE EXPERIMENTS AT HOBOKEN, APRIL AND MAY, 1878.—CALCULATED t_0.

HEAVY END UP.													HEAVY END DOWN.					
φ	April 24. (Pr. 1.24.)	April 26. (Pr. 2.25.)	April 24.	April 26.	April 26.	April 30.	April 30.	May 2.	May 2.	May 10.	May 10.	May 11.	May 11.	φ	May 4.	May 5.	May 6.	φ	May 8.
′	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	′	m.	m.	m.	′	m.
.0336	......	......	......	......	−4.6	......	......	......	......	......	......	......	......	......	......	......	......	......	......
326	......	......	......	......	4.7	......	−24.2	......	......	......	......	......	......	.032	+38.5	......	......	.03265	+0.4
316	......	......	......	......	......	......	24.2	......	r−24.6	......	......	......	......	31	38.5	......	......	3165	0.3
306	......	......	......	......	4.3	......	24.1	+19.2	......	......	−30.3	......	+0.2	30	38.5	+46.5	......	3065	0.3
296	246.8	......	......	......	4.5	......	24.3	19.3	−23.9	......	30.4	......	0.1	29	38.5	46.4	......	2965	0.6
286	245.5	......	......	......	......	+20.9	24.1	19.2	......	......	......	......	0.0	28	38.4	46.3	+58.1	2865	0.4
276	245.3	......	......	−23.6	......	21.0	24.0	19.4	23.9	+15.3	30.3	−14.4	0.0	27	......	46.4	......	2765	0.3
266	244.5	......	......	23.5	4.3	20.9	......	19.4	23.9	15.1	......	14.7	0.1	26	......	46.4	58.4	2665	......
256	243.8	......	......	23.3	4.4	21.1	......	19.3	......	......	30.2	14.8	0.0	25	38.2	......	58.4	2565	......
246	244.3	......	+17.5	23.4	4.3	21.0	......	r18.5	......	15.2	30.2	14.8	......	24	38.4	46.8	......	2465	0.6
236	......	223.6	17.6	......	4.4	......	......	......	23.8	......	......	14.8	......	23	38.6	46.9	......	2365	0.7
226	......	223.2	17.2	......	4.3	......	24.1	......	23.7	......	......	......	0.0	22	38.7	46.9	58.0	2265	0.5
216	......	222.0	......	......	4.4	21.0	24.1	......	23.7	......	30.1	......	0.1	21	38.9	47.1	58.6	2165	0.6
206	......	222.1	......	23.0	4.2	20.9	24.1	19.8	23.6	15.4	30.1	14.6	0.0	20	38.9	47.3	58.9	2065	0.6
196	......	221.5	......	23.2	4.2	21.1	24.1	19.8	23.7	15.3	30.2	14.7	0.1	19	38.7	47.3	59.0	1965	0.5
186	......	221.2	17.3	23.0	......	21.2	23.9	20.0	23.4	15.5	30.1	14.6	0.1	18	38.8	47.2	59.2	1865	+0.9:
176	......	......	17.4	23.2	3.9	21.3	23.9	......	......	15.5	30.1	14.6	0.1	17	......	47.5	......	1765	......
166	......	......	17.9	23.1	3.8	21.2	......	20.0	23.1	15.6	30.2	14.5	0.3	16	39.0	......	60.1	1665	−0.1
156	......	221.6	17.7	......	4.1	......	23.8	20.2	23.2	......	......	......	......	15	39.5	47.9	60.6	1565	+0.1
146	......	221.0	......	22.7	3.8	21.4	23.8	20.3	23.1	15.9	29.8	14.3	0.3	14	39.4	48.2	60.6	1465	0.4
136	......	222.0	17.7	22.6	3.8	21.6	23.8	......	22.9	15.8	29.9	14.3	0.4	13	39.6	48.5	60.5	1365	0.5
126	......	221.7	......	22.5	3.5	21.6	23.6	......	22.6	15.8	29.8	14.2	0.4	12	39.8	49.1	......	1265	0.5
116	......	222.2	18.0	22.4	3.3	21.8	23.5	21.2	22.4	16.1	29.6	14.2	0.3	11	39.9	......	......	1165	0.1
106	......	......	18.3	22.4	3.1	22.2	23.2	21.3	21.9	16.2	29.5	14.0	0.5	10	......	......	......	1065	+0.3
096	......	......	18.1	......	3.0	22.6	22.8	21.6	−21.6	16.4	29.5	13.8	0.8	09	......	......	......	.00965	−0.4
086	......	......	18.2	−22.6	−2.8	22.7	−23.0	21.8	......	16.4	−29.1	13.7	0.5	08	......	......	+59.1		
.0076	......	......	+17.9	......	......	+22.6	......	+22.2	......	+16.6	......	−13.6	+1.0?	.007	+41.9	+51.1	......		

REDUCTION TO A VACUUM.

It is not usual to reduce observations with the reversible pendulum to a vacuum, because the formula for combining the results with heavy end up and heavy end down, namely,

$$T = \frac{T_d\, h_d - T_u\, h_u}{h_d - h_u},$$

is supposed to eliminate the atmospheric effect; and it really does so if the hollow bob is staunch. Nevertheless, there is a great advantage in reducing to a vacuum, for in that way we may use the reversible pendulum as two invariable pendulums, combining them by the formula

$$T = \frac{T_d\, h_d + T_u\, h_u}{h_d + h_u}.$$

In our pendulum $h_d : h_u = 7 : 3$; hence, the usual formula gives a T which is subject to $\frac{7}{4}$ of the error of T_d and $\frac{3}{4}$ of the error of T_u, while the proposed formula gives a T which is subject to only $\frac{7}{10}$ of the error of T_d and $\frac{3}{10}$ of the error of T_u, so that its error is only $\frac{4}{10}$ of that of the other. It is true that it is somewhat difficult to ascertain the amount of the atmospheric correction which must be applied before the second formula can be used, but it will be shown that it is not impossible. Nor will it be subject to any uncertainty which will be sensible unless under changes of pressure amounting to a considerable fraction of an atmosphere.

But if this is so, it may be asked, why use a reversible pendulum at all? The reply is, that we have thus a continual check upon our work; and also a means of studying knife-edge effects, etc. Moreover, the fatal effect of any accident to the pendulum is thus insured against. Another advantage of the reversible pendulum is that the center of oscillation can be ascertained with exactitude, its position being a necessary datum for calculating the effect of the atmosphere.

The presence of the air lengthens the period of oscillation of the pendulum in no less than four distinct ways: 1st, by its buoyancy; 2d, by being carried along within inclosed parts of the pendulum; 3d, by the hydrodynamic effect of its pressure; and 4th, by its viscosity.

In reckoning the buoyancy of the air, it will make a good deal of difference whether the hollow bob is open or tightly closed. It should be quite staunch; otherwise, the atmospheric effect is not eliminated. If it be so, the air it contains is to be considered as a part of the pendulum; otherwise, not. It is believed that our hollow bob is tight. To ascertain the volume of this air, we have to consider that if the hollow were filled with brass the center of mass would be at the center of figure. The existing brass whose center is at a distance $\frac{1}{2}(h_d - h_u)$ from the center of figure and the brass which would be required to fill the hollow bob and which would be at the distance, say o (which can be measured), from the center of figure, would then be in equilibrium about the center of figure. Hence, their volumes are in the ratio of $\frac{1}{2}(h_d - h_u)$ to o. It is necessary to assume a density for the air in the bob. Then the mass of the pendulum obtained by weighing and corrected for the buoyancy of brass in air must be further increased by the mass of air in the hollow bob, by multiplying it by

$$\left(1 + \frac{\frac{1}{2}(h_d - h_u)}{o}\frac{\rho_3}{\rho_1}\right),$$

where ρ_3 is the supposed density of this air and ρ_1 is that of brass; and this corrected mass of the pendulum must be used in all the corrections affecting the inertia. The value of $h_d - h_u$ must also be diminished by the ratio of the mass of air in the bob to the corrected mass of the pendulum multiplied by $(2\,o + h_d - h_u)$. These corrections being applied we shall have (putting ρ_2 for the density of the circumambient air)

$$T_d = \circlearrowleft \sqrt{\frac{l}{g}} \cdot \left(1 + \tfrac{1}{4}\frac{h_d + h_u}{h_d}\left[1 + \left(1 - \frac{\rho_3}{\rho_1}\right)\frac{h_d - h_u}{2o}\right]\frac{\rho_2}{\rho_1}\right),$$

and a similar formula will hold for T_u replacing h_d by h_u in the denominator.

Besides the air in the hollow bob, a large volume is inclosed within the open tube which forms the stem of the pendulum. The volume has to be calculated from the measured dimensions of the tube. Let this volume be σ_2 and let its radius of gyration about the center of mass be γ_2; then the formula for the period will be, with heavy end down,

$$T_d = \circlearrowleft \sqrt{\frac{l}{g}}\left(1 + \frac{\sigma_2\rho_2\left[\gamma_2^2 + \frac{1}{4}(h_d + h_u)^2\right]}{M\,l\,h_d}\right),$$

and with heavy end up the same formula will hold after substituting h_u for h_d in the denominator. The $l\,h_d$ in the denominator is best replaced by $(\Gamma^2 + h_d^2)$ where Γ is the radius of gyration of the pendulum about its center of mass. This quantity can be ascertained by an approximate reduction of the times of oscillation to a vacuum.

Thirdly, the ordinary pressure of the atmosphere, due to its weight, makes the pendulum carry air with it, and increases its inertia. This effect was first discovered by du Buat, but particular attention was brought to it by Bessel. It has been subjected to mathematical analysis by Green, who has given the formula for the period of oscillation of any ellipsoid making oscillations, very small as compared with its own dimensions, in an infinite incompressible fluid. The air is sufficiently incompressible under the gentle movement of the pendulum, and the limitation to very

small oscillations, though particularly insisted on by Green, is probably immaterial. His formula is as follows:

Let the equation of the ellipsoid be

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1$$

and let x be in the direction of the oscillations. Then calculate the quantity

$$\mathrm{F}=\tfrac{1}{2}\,a\,b\,c\int_0^\infty\frac{\mathrm{d}f}{\sqrt{(a^2+f)^3\,(b^2+f)\,(c^2+f)}}$$

and the effect in question will be as if the inertia of the ellipsoid were increased by $\frac{\mathrm{F}}{1-\mathrm{F}}\cdot\frac{\rho_2}{\rho_1}$. When the ellipsoid is one of revolution, the integration can be effected in finite terms.

If $a=c$ (that is, if the oscillation is in the equatorial plane) put $\frac{b}{a}=\cos\omega$, and we have

$$\mathrm{F}=\tfrac{1}{2}\operatorname{cotan}^2\omega\left(\frac{2\,\omega}{\sin 2\,\omega}-1\right).$$

This formula is suitable for an oblate spheroid. If it is prolate, imaginaries are avoided by putting $\frac{a}{b}=\cos\omega$, when

$$\mathrm{F}=\tfrac{1}{2}\operatorname{cosec}^2\omega\left(1-\cos\omega\,.\operatorname{cotan}\omega\,.\log\tan\left(\frac{\pi}{4}+\frac{\omega}{2}\right)\right)$$

If $b=c$ (that is, if the oscillations are on the polar axis), put $\frac{b}{a}=\cos\omega$, and we have

$$\mathrm{F}=\cot^2\omega\left(\operatorname{cosec}\omega\,.\log\tan\left(\frac{\pi}{4}+\frac{\omega}{2}\right)-1\right).$$

This formula is suitable for a prolate spheroid; for an oblate one, put $\frac{a}{b}=\cos\omega$ and we have,

$$\mathrm{F}=\operatorname{cosec}^2\omega\left(1-\frac{\omega}{\tan\omega}\right).$$

When the ellipsoid becomes an infinite cylinder swinging transversely, we readily see by the second equation that $\mathrm{F}=\frac{1}{2}$, and the coefficient of the effect is unity. In the case of a sphere, all the equations have indeterminate forms. We may consider the last as being the simplest. When ω is made infinitesimal this becomes

$$\mathrm{F}=\frac{1}{\omega^2\,(1-\frac{1}{6}\,\omega^2)^2}\left(1-\frac{\omega}{\omega(1+\frac{1}{3}\,\omega^2)}\right)=\tfrac{1}{3}.$$

Hence, the coefficient of the effect is $\frac{1}{2}$. In the case of a plane oscillating tangentially, the first equation shows that F is a zero of the second order, so that not merely the coefficient, but also the whole effect, vanishes. The same is true of a cylinder oscillating longitudinally. In the case of a circular disk oscillating normally, we have to put in the last equation $\omega=\frac{\pi}{2}$. It will be convenient to substitute $\psi=\frac{\pi}{2}-\omega$ and then put ψ infinitesimal. This gives us

$$\begin{aligned}\mathrm{F}&=\sec^2\psi\left(1-\left(\frac{\pi}{2}-\psi\right)\tan\psi\right)\\&=1-\frac{\pi}{2}\,\psi\end{aligned}$$

Then, the coefficient of the effect is

$$\frac{F}{1-F} = \frac{2}{\odot}\frac{1}{\psi}$$

If R be the radius of the disk, the volume of the infinitesimally thin spheroid is $\frac{4}{3} R^3 \psi$. Hence, the effect is $\frac{2}{\odot}\frac{4}{3} R^3$. The effect for the sphere erected on the circle is $\frac{1}{2}\frac{4}{3} R^3$. So that we find that the effect of the circular disk is $\frac{4}{\odot}$ that of the sphere erected on it.

The following little table will show the run of the function:

Ratio of polar to equatorial diameter.	Equatorial oscillations. Ratio of hydrodynamic effect to buoyancy.	Equatorial oscillations. Ratios of successive coefficients.	Polar oscillations. Ratio of hydrodynamic effect to buoyancy.	Polar oscillations. Ratios of successive coefficients.
0	0.000		.∞	
¼	0.174		2.374	
		1.78		$\frac{1}{2.13}$
½	0.310		1.115	
		1.61		$\frac{1}{2.23}$
1	0.500		0.500	
		1.14		$\frac{1}{2.38}$
2	0.704		0.210	
		1.22		$\frac{1}{2.56}$
4	0.860		0.082	
∞	1.000		0.000	

On examining this table, we see that, in reference to equatorial oscillations, 1st, the flatter the spheroid the less the resistance not only absolutely but relatively to the displacement (or cross-section, which, in this case, is in the same proportion); 2d, that this change of the coëfficient with a change of shape of the spheroid is greater and greater the flatter the spheroid and less and less the longer it is, until it must soon become insensible. This shows that a moderately long cylinder may be treated as infinitely long; nay, more, that a moderately long ellipsoid may be treated as an infinite cylinder, the small amount of air which flows over its ends not relieving the flow of the rest, perceptibly. But the flatter the ellipsoid the sharper becomes its edge, which quickly sheds the air. A short ellipsoid thus bears but a very slight resemblance to a short cylinder which has no such edge. Yet a large proportion of air must flow over the ends of a short cylinder. Accordingly, in the absence of any mathematical analysis, it is difficult to treat an object of this form. The effect of the shedding of the air is shown in the table relating to polar oscillations. We see here that the more prolate spheroids not only resist less proportionally to their bulk (the cross-section remaining the same), but also less absolutely. The ratios of successive numbers here for bodies nearly spherical are about the squares of those in the other table. Here, as before, the sharper the points the greater and greater is the effect of further sharpening, and *vice versa*. When the spheroid is moderately flat the absolute hydrodynamic effect is nearly the same as for a circular disk; when it is moderately pointed the effect, relative to its volume, is very small, but, in comparison to its own magnitude, is very variable.

A rough estimate of the effect on a short cylinder oscillating transversely may be obtained as follows: First, compare the effects on a sphere and a cylinder having the same volume and resisting section. The ratio of the diameter to the altitude of such a cylinder will be $\frac{9}{128}\odot^3$, or nearly 1.09. This cylinder will undoubtedly have a greater resistance than the sphere and less than a circular disk equal to the diametral section of the sphere. But the effect on the disk is only $\frac{4}{\odot}$, or

about 1.27; so that if we take the effect on the cylinder as 1.18 (for it must be somewhat nearer that on the disk), we cannot be very far out. This would be supposing it to carry 0.59 of its displaced air. This is about the same that is carried by a prolate ellipsoid whose axes are in the ratio of $\sqrt{2}:1$. A shorter cylinder must carry less air and a longer one more, relatively to the volume. But the difference cannot be so great as the difference of ellipsoids from the sphere. We may consistently suppose that every cylinder carries as much air as a spheroid of the same volume, the ratio of whose polar axis to its equatorial diameter is $\sqrt{2} \times 1.09$, or 1.54 that of the ratio of the altitude to the diameter of the cylinder.

Stokes has shown that the hydrodynamic effect is largely increased by the walls of the vessel containing the pendulum. In the case of a sphere of radius a in a spherical vessel of radius b, the ratio of increment is $\frac{b^3 + 2a^3}{b^3 - a^3}$. In the case of an infinite cylinder in a concentric vessel, the ratio is $\frac{b^2 + a^2}{b^2 - a^2}$. For large values of b these expressions coincide. The case of an ellipsoid in a cylindrical vessel has not been solved; but an estimate of the effect may be made, as follows: A cylindrical vessel would probably act on an oscillating sphere to one-half the amount of a spherical vessel of the same diameter; but if the oscillating body is an oblate spheroid, whose polar axis coincides with that of the vessel, the vessel has relatively less effect, because most of the air escapes in that direction. In the case of a sphere, half the air escapes toward the sides and half to the top and bottom. If the ellipsoid, instead of having the coefficient of the hydrodynamical effect $\frac{1}{2}$, like the sphere, has only $\frac{1}{3}$, we may say that only $\frac{1}{3}$ escapes in the equatorial direction and is affected by the cylindrical envelope. In general, therefore, we may estimate this small quantity sufficiently by multiplying the correction for the sphere in a spherical envelope by the coefficient of the hydrodynamic effect.

In the fourth place, even if the air had no weight and consequently no statical pressure, it would still affect the motion of the pendulum in virtue of its *viscosity*. This effect forms the subject of a fine investigation by Stokes. He shows that the viscosity of the air causes a decrement of the amplitude in a constant ratio. This is the cause of the phenomenon represented by the second term of the equation

$$\mathrm{D}_t \Phi = -a - b\,\Phi - c\,\Phi^2.$$

In the case of an oscillating sphere this part of the decrement consists entirely of two terms, one proportional to the square root of the viscosity and the other to the viscosity itself. In the case of an infinite cylinder, two similar terms constitute the bulk of the effect. In the case of a plane oscillating tangentially, only the term proportional to the square root of the viscosity appears. In all three cases the formulæ of Professor Stokes exhibit a remarkable relation between the effect on the decrement of the arc and the effect on the period of oscillation; namely, that that term of the former which is proportional to the square root of the viscosity is identical with the only considerable term of the latter. In fact, the viscosity introduces into the differential equation of the motion a term in $\frac{\mathrm{d}s}{\mathrm{d}t}$ and a term in $\frac{\mathrm{d}^2 s}{\mathrm{d}t^2}$. The former of these has a part which varies as the square root of the viscosity, and the coefficient of this part is equal to the coefficient of the term in $\frac{\mathrm{d}^2 s}{\mathrm{d}t^2}$.

By the viscosity is here meant what Stokes terms the index of internal friction and Maxwell the kinematical viscosity. It is the quotient of the retardation of the velocity at any point of the fluid caused by the excess of the velocity at this point over the mean velocity in the neighborhood divided by this excess. Analytically defined, it is

$$\mu^1 = \frac{\dot{v}}{\left(\frac{d^2}{dx^2} + \frac{d^2}{dy^2} + \frac{d^2}{dz^2}\right) v}.$$

The dependence of the viscosity of air upon its pressure and temperature has been one of the chief objects of physical inquiry in our day. That it is inversely proportional to the pressure is fully established, this being equally the prediction of the kinetical theory of gases and the result of all the experiments, whether those by Graham and Meyer and Springmühl on transpiration, or those of Maxwell and others on the oscillation of plane surfaces. In respect to the dependence upon temperature, opinion does not seem to be quite unanimous. Nevertheless, the experiments of von Obermayer, of Kundt and Warburg, of Wiedemann, of Holman, and of Puluj, all concur in showing that, in the case of air, the viscosity as here defined varies nearly as the $\frac{3}{4}$ power of the absolute temperature.

Inasmuch as the function of the viscosity always appears in the formulæ multiplied by the density of the air, it follows that the logarithmic part of the decrement will appear as two terms. Namely, for heavy end down

$$b_d = \frac{k_1}{l\,h_d}\,\tau^{\frac{3}{4}} + \frac{k_2}{l\,h_d}\,\frac{\sqrt{p}}{\sqrt[8]{\tau}},$$

and for heavy end up,

$$b_u = \frac{k_1}{l\,h_u}\,\tau^{\frac{3}{4}} + \frac{k_2}{l\,h_u}\,\frac{\sqrt{p}}{\sqrt[8]{\tau}}.$$

And the effect of the resistance on the period of oscillation will be for heavy end down

$$\Delta\mathrm{T} = \frac{\mathrm{T}}{\circledcirc}\,\frac{k_2}{l\,h_d}\,\frac{\sqrt{p}}{\sqrt[8]{\tau}},$$

and for heavy end up,

$$\Delta\mathrm{T} = \frac{\mathrm{T}}{\circledcirc}\,\frac{k_2}{l\,h_u}\,\frac{\sqrt{p}}{\sqrt[8]{\tau}}.$$

It must be remembered that this supposes b to be expressed in parts of the radius, it being an angular quantity.

The theory of Stokes supposes that the friction between the air and the pendulum is not infinitely less than that between two layers of air, so that no slipping of the air over the pendulum can take place. He adduces some facts in support of this hypothesis, but Messrs. Kundt and Warburg showed in 1875 that this is not true. It is, however, easy to show from their observations that the amount of slipping is insignificant. They find, in fact, that the coefficient of slipping, which is the depth to which the solid must be considered to be composed of air in order to account, on the hypothesis of no slipping, for the degree of motion on its surface, is inversely proportional to the density and is at ordinary pressure and at the freezing-point of water equal to $\frac{1}{10}$ of a micron. Consequently, even at a pressure of only $\frac{1}{3}$ of an inch it would only amount to $\frac{1}{100}$ mm. Now, as the radius of the stem of the pendulum is 2 cm, the friction could not be reduced by this slipping more than $\frac{1}{1000}$ part, which is quite imperceptible.

It has been rendered probable by Stokes that a large envelope about the pendulum will not much affect this correction, but this will not probably be the case when the pendulum approaches near to the envelope in swinging, and the rate of decrement is our only guide in the matter.

It is, now, necessary to apply the general formulæ to the calculation of the values of the coefficients of the atmospheric corrections.

The effect of the buoyancy of the brass is half the ratio of the moment of gravity on the displaced air to its moment on the pendulum. All these calculations will be made in C. G. S. absolute units. We are, however, unacquainted with the absolute unit of temperature, and it becomes necessary to adopt one. The unit chosen will be $273^\circ + 15^\circ = 288^\circ$ of the Centigrade scale; so that the absolute zero being taken as zero, 15° C. will be a temperature of unity. This choice is made because 15° C. is the mean temperature at which it is desirable to make pendulum-experiments. Centigrade degrees will always be spoken of, but τ in the formulæ and calculation will denote the absolute temperature divided by 288 Centigrade degrees above the absolute zero. The coefficients of pressure will relate to ONE ABSOLUTE ATMOSPHERE, by which is meant one million

grammes per centimeter (second)^2. This may be converted into the pressure of a height of mercury by a calculation like the following:

	Names of quantities.	Numbers.	Logarithms.
	Density mercury at 0° C. compared with water at 4°	13.5959	1.133405
	Absolute density of water at 4°	0.99999 $\frac{gr}{(cm)^3}$	—4
∴ Multiplying,	Absolute density of mercury at 0°	13.5957 $\frac{gr}{(cm)^3}$	1.133401
	Gravity at Paris (60^m elevation)	980.88 $\frac{cm}{s^2}$	2.991616
∴ Multiplying,	Absolute specific gravity of mercury at Paris	13335.7 $\frac{gr}{cm(s)^2}$	4.125017
	One absolute atmosphere	1000000 $\frac{gr}{cm(s)^2}$	6.000000
∴ Dividing,	One absolute atmosphere expressed in centimeters, pressure of mercury at 0° at Paris at elevation of 60^m	74.986	1.874983

This is equal to 29.63 inches pressure at Hoboken at 15° C. At London it is less by 0.03 inch, a quantity which produces hardly a perceptible effect in the time of oscillation of the pendulum.

To find the density of the air under this pressure, we have, according to the experiments of Regnault (Wüllner's Experimentalphysik, 3ter Band, 3te Auflage, S. 133), the absolute density of dry air free from CO_2 at 0° C. and pressure 76 cm at Paris (6^m elevation), 0.0012932. This supposes a slightly different absolute density of water from that above assumed; but that is a matter of no consequence. Then we have

		Log.
Density dry pure air at Paris, standard atmosphere	.0012932	7.11167
Centimeters, pressure in Paris, standard	76	1.88081
Centimeters in absolute atmosphere	74.986	1.87498
∴ Density pure dry air at 0° C. under one absolute atmosphere	.0012760	7.10584
Absolute temperature of 0° C. = $\frac{273}{288}$		9.97677
∴ Density pure dry air at 15° C. under one absolute atmosphere	.0012095	7.08261
Correction for usual amount CO_2 $(1 + .529 \times 4 \times 10^{-4})$		0.00009
∴ Density common dry air at 15° C. under one absolute atmosphere	.0012097	7.08270

The moisture was not observed during the pendulum-experiments but is believed to have been as much as would be contained in air at a little less than ½ saturation at 15°; or say that the density was diminished by 3 thousandths. The density of the air taken may then be taken at .001206 at 15° C. under a pressure of one absolute atmosphere.

Our pendulum never having been weighed in water, it is necessary to estimate its density. The brass of which it is composed may be supposed to be of the same density as that of the Prussian pendulum-meter, which density is given by Bruhns as 8.5. But the pendulum contains a certain amount of steel. The knives have as their dimensions $9.55 \times 1.8 \times 1.4$, the product being 24 (cm)^3. A part is beveled off, but other steel about the pendulum will make up nearly the amount. The entire volume of steel would be therefore 48 (cm)^3. We may take it at 45 (cm)^3. Assigning to steel the density 7.82 the mass of steel would be 352 gr. The entire mass of the pendulum has been ascertained by weighing to be 6308 grammes. Subtracting the mass of the steel, we have for that of the brass 5956 grammes. Dividing this by the assumed density of the brass we have 701 (cm)^3 as the volume of brass, and 746 (cm)^3 as the total volume of the metal in the pendulum. Then for the density of the metal we have $\frac{6308}{746}$ or $8.46 \frac{gr}{(cm)^3}$.

But a part of the pendulum is the air within the hollow bob. To find the volume of this, we have the following data, obtained by measurement:

$$h_d - h_u = 39.292$$
$$o \quad = 59.25$$

We then calculate as follows:

$\frac{1}{2}(h_d - h_u)$	19.696	1.29438
o	59.25	1.77269
Ratio volume hollow to that of metal	0.3324	9.52169
Volume metal	746	2.87276
Volume hollow	248	2.39443

The accuracy of this calculation can be checked by another. The hollow of the bob is a cylindrical ring. The thickness of the metal is said to be 0.1 cm. The exterior diameter of the bob is by accurate measurement 11.4 cm. Its interior diameter would, therefore, be 11.2 cm. The exterior diameter of the stem on which this ring fits is 4.35. Then the inner diameter of the hollow ring would be 4.55 cm. The exterior height of the bob is 3.175 cm; then, its inner height would be 2.975. Calculation from these data gives as the volume of the hollow 243 (cm)^3; thus confirming, in some measure, the density of brass assumed.

The total volume of the pendulum, so calculated, is 994 (cm)^3. Then the absolute density of the whole is 6.35 $\frac{\text{gr}}{(\text{cm})^3}$. And the ratio of the density of air at 15° and under pressure of one absolute atmosphere to that of the pendulum is $\frac{.001206}{6.35}$ .0001900. To get the effect of buoyancy with heavy end down and up, this ratio is to be multiplied by one-fourth the distance between the knife-edges (which is 100.01 cm), divided by the distance of the center of mass from the point of support. This gives, for heavy end down and up, .0000682 T_d, and .0001565 T_u. Even should the density of the brass be in error by 2 per cent., the resulting error in the relative gravity of two stations, where the barometric difference was 5 inches, would be inappreciable with heavy end up (much more with heavy end down) in the sixth place of decimals.

All the remaining parts of the atmospheric effect are inversely proportional to the moment of inertia of the pendulum. Experiments to be described below show that in vacuo at Hoboken at 15° C.

$$T_d^2 = 1.012045$$
$$T_u^2 = 1.011465$$
$$T_d^2 - T_u^2 = .000380$$
$$\tfrac{1}{2}(T_d^2 + T_u)^2 \quad 1.011755$$

Then it follows that the square of the radius of gyration about the center of mass is

$$h_d\, h_u \left(1 + \frac{T_u^2 + T_d^2}{T_u^2 - T_d^2}^{2} - \frac{h_d - h_u}{h_d + h_u} \right)$$

From this we find the two radii of gyration to be $\sqrt{6963.0}$ and $\sqrt{3033.3}$ centimeters; and the two moments of inertia, the mass being 6308 gr, are 4392×10^4 gr (cm)^2 and 1913×10^4 gr (cm)^2.

To find the effect of the air in the tube forming the stem of the pendulum, we have the following data:

	Centimeters.
Diameter of tube	3.99
Length	123.6
Distance center to knife	50.00
Square of radius of gyration of the pendulum about its center of mass parallel to knife-edges	2111

This gives for the solid contents of the tube 1515 $(\text{cm})^3$, for the square of the radius of gyration is—

$$(50.00)^2 + \tfrac{1}{4}\left(\frac{(3.99)^2}{4} + \frac{(123.6)^2}{3}\right) = 3774\ (\text{cm})^2.$$

The two moments of inertia of the pendulum are, with heavy end down, 4387×10^4 gr. $\times$ $(\text{cm})^2$, and with heavy end up 1911×10^4 gr $\times$ $(\text{cm})^2$. Whence the effect of this air is to add to the times of oscillation .0000786 T_d and .0001807 T_u, respectively.

We come now to the hydrodynamic effect. The greater part of this is due to the stem of the pendulum. This is a cylinder whose dimensions are—

	Centimeters.
Length	123.8
Diameter	4.33

From these data the solid contents are found to be 1823 $(\text{cm})^3$. Its radius of gyration being slightly greater than that of the tube, may be taken at $\sqrt{3779}$ cm. Then, the air having the standard density, the moment of inertia is 8310 gr $(\text{cm})^2$, and the effects on the periods of oscillation will be

$$.0000946\ T_d \text{ and } .0002169\ T_u.$$

When the pendulum is on the Geneva stand, the effect of the walls of the cylinder have to be taken into account. If the bells are not on, only the 90 middle centimeters of the stem are affected. The square of the radius of gyration is thus reduced to 3176 $(\text{cm})^2$, only 84 per cent. of that of the whole cylinder. The solid contents are only .727 of the whole, and hence the affected moment of inertia is only $.727 \times .84 = .61$ of the whole. The diameter of the cylinder is 25 cm. Hence, the coefficient of correction is $2\,\frac{(4.33)^2}{(25)^2 - (4.33)^2} \times .61 = .0377$; which gives for heavy end down and up

$$.0000036\ T_d \text{ and } .0000081\ T_u.$$

But when the bells are on the whole is affected, and the corrections are

$$.0000058\ T_d \text{ and } .0000134\ T_u.$$

The two bobs are not precisely of the same size. Their dimensions are

	SOLID BOB. Centimeters.	HOLLOW BOB. Centimeters.
Diameter	11.48	11.42
Height	3.25	3.18

Their solid contents are

$$336.3\ (\text{cm})^3 \qquad 325.0\ (\text{cm})^3.$$

But a part of this volume has already been reckoned as a part of the stem of the pendulum. Owing to the influence of the re-entrant angle at the junction of the bob and stem, which must cause an increase of the effect, it will be better to leave this core as a part of the stem than to include it in the bob. The volume of this core is

$$\circledcirc\ (4.33)^2\ (3.18) = 46.8\ (\text{cm})^3 \text{ for the light bob}$$
$$\text{and } \circledcirc\ (4.33)^2\ (2.25) = 47.9\ (\text{cm})^3 \text{ for the heavy one.}$$

Subtract these from the volumes already obtained, we get as the true volumes

278.2 $(\text{cm})^3$ for the light bob
and 288.4 $(\text{cm})^3$ for the heavy one.

The squares of the radii of gyration of these bobs about their centers of mass, parallel to the knife-edges, are

$$\tfrac{1}{4}\left(\frac{(4.33)^2 + (11.42)^2}{4} + \frac{(3.18)^2}{3}\right) = 10.16\ (\mathrm{cm})^2$$

$$\tfrac{1}{4}\left(\frac{(4.33)^2 + (11.48)^2}{4} + \frac{(3.25)^2}{3}\right) = 10.29\ (\mathrm{cm})^2.$$

The center of each bob is distant 9.283 cm. from the nearest knife-edge. Hence, the squares of the radii of gyration about the near knife-edges are

$$(9.283)^2 + 10.16 = 96.33\ (\mathrm{cm})^2 \text{ for the light bob.}$$
$$(9.283)^2 + 10.29 = 96.46\ (\mathrm{cm}) \text{ for the heavy bob.}$$

And about the far edges the value for both is

$$(109.28)^2 + 10 = 11954\ (\mathrm{cm})^2.$$

Then, using the standard density of air, we find for the moment of inertia of the air displaced by both bobs, with heavy end down, 4190 gr $(\mathrm{cm})^2$, and with heavy end up, 4045 gr $(\mathrm{cm})^2$.

To calculate what proportion of the displaced air is to be considered as carried along, we first find the ratios of the axes of both cylinders. These are—

For the light bob	.278
For the solid bob	.283

These are to be multiplied by 1.54, to find the cosine ω. We thus find ω for light bob 64°.6 and for the heavy bob 64°.1. Hence, we find, by Green's formula, for the coefficient of the effect, .278 for the solid bob and .272 for the hollow one. This gives for the effective moments of inertia,

With heavy end down	1244 gr. $(\mathrm{cm})^2$
With heavy end up	1185 gr. $(\mathrm{cm})^2$.

Whence, the effects on the time of oscillation are

$$.0000141\ T_d \text{ and } .0000310\ T_u.$$

Putting 27 cm as the diameter of the bell-glasses of the Geneva support, it appears that their effects upon the correction for the bob are

$$.0000021\ T_d \text{ and } .0000046\ T_u.$$

We have now taken account of the following amounts of displaced air:

Displaced by the stem	1823 $(\mathrm{cm})^3$
Displaced by the light bob	278
Displaced by the heavy bob	288
Total	2389 $(\mathrm{cm})^3$

But the whole amount displaced by the pendulum may be reckoned thus—

Displaced by metal	746 $(\mathrm{cm})^3$
Displaced by hollow of bob	248
Contents of tube of stem	1533
Inclosed in frames	16
Total	2543 $(\mathrm{cm})^3$

There remain, therefore, 154 $(\mathrm{cm})^3$ displaced by the knives, and apparatus for holding them, by the collars which secure the bobs, and by the little cylinders at the ends of the pendulum. The

position of the center of mass of this air may be estimated as 3 cm outside the knife-edges and its radius of gyration about its center as 2 cm. The hydrodynamic effect should be taken as equivalent to carrying the displaced air, as a part of this air enlarges the cylindrical stem and the rest is so shaped as to offer very great resistance. Hence the effects are

$$.0000105\ T_d \text{ and } .0000241\ T_u.$$

If we, now, add together the various parts of the effects of buoyancy, of inclosed air, and of air carried outside, we have the total calculable effect proportional to the atmospheric density, as follows:

	Heavy end down.	Heavy end up.
Buoyancy	682×10^{-7}	1565×10^{-7}
Air within stem	795	1826
Air within frames	24	70
Air without stem	946	2169
Air without bobs	141	310
Air without knives, etc	105	241
Sums	2693	6181

When the pendulum swings upon the Geneva support without the bell-glasses we have to increase these effects by

Effect of cylinders	36	71
Sums	2729	6252

When the bell-glasses are in place we have in addition

Effect of bells on stem	22	53
Effect of bells on bobs	21	46
Sums	2772	6351

The result of this calculation is probably a little too small, owing to neglected terms, and can hardly be too large.

The calculation of the effect of viscosity on the time of oscillation depends on the variation of the decrement of the arc with the pressure. Experiments were made upon the Geneva support at Hoboken at various pressures. The observations of arc made during these observations, as has been explained above, were reduced according to the formula

$$\dot{\Phi} = -b\,\Phi - c\,\Phi^2\,,$$

a being supposed zero in order to diminish the number of unknown quantities. The coefficient c was supposed proportional to the density and one factor was taken for all the experiments, while b was left to be determined independently for each. The result is that all the abnormal variations of the decrement which are considerable are thrown upon b, so that the latter presents an appearance of greater irregularity than properly belongs to it. The results of these experiments are shown in illustration No. 37 *c*. Those with heavy end down have been brought to heavy end up by multiplying them by $\frac{h_d}{h_u}$. The time is expressed in minutes; the pressure in inches pressure at 15° C. at Hoboken. It will be seen that the observations satisfy sufficiently well the formula

$$b = .0013\ \tau^{\frac{3}{4}} + .00435\ p^{\frac{1}{2}}\ \tau^{-\frac{1}{2}}.$$

When the bell-glasses were removed, the time of decrement was noticeably increased; but this is partly due to the change in the value of c. Upon the Repsold support there is scarcely any sensible difference between the time of decrement from that in experiments of the Geneva support with the bells removed. This is shown on illustration No. 36. To compare the observations of arc at

Paris, Berlin, and Kew, with those at Hoboken, they were recalculated with only three constants. These as corrected by least squares are

$$b = .0001082 \quad \text{(units: one second of time and one minute of arc.)}$$
$$c = .000001125$$

t_0, reckoning from $1^\circ\ 10' = 8001^s$. The agreement of these values with observation is shown below:

φ (Obs.)	φ (Calc.)	C − O
130′	129′.96	− 0′.04
110	109 .85	− .15
100	100 .17	+ .17
80	80 .05	+ .05
70	69 .89	− .11
50	49 .91	− .09
40	40 .12	+ .12

Reduced to decimal parts of radius, minutes of time and heavy end up, these values become

$$b = 0.0214, \qquad c = 0.76.$$

Observations of June, 1877, at Hoboken, give

$$b = 0.0242, \qquad c = 0.58.$$

Allowing the European observations a weight of 3 and combining the values of c, we have

$$c = 0.72.$$

Substituting this value, we find for b at Paris, Berlin, and Kew........................ 0.0224
And at Hoboken... 0.0212
b (weighted mean)..................................... = 0.0221

The curve drawn in illustration No. 36 is calculated from the European coefficients, and the agreement of the observations taken at Hoboken before the bell-glasses were put on is shown by the near coincidence with it of the points distinguished by crosses. The points distinguished by circles are obtained from a combination of all the observations taken in 1877 with the bells on, when the pressure was about 30 inches. The t_0 taken in each case was the one that made the mean excess over the curve equal to zero. The influence of the bell-glasses in arresting the motion of the pendulum is thus very strikingly shown. The value of b, with the bells on, under a pressure of 30 inches, appears by the above formula to be 0.0251 for a minute of time. The mean of the experiments with bells off, as just shown, gives $b = .0221$; so that we may assume that the viscosity effect is one-seventh larger with the bells on than off.

To calculate the effect on the period of oscillation, we take the coefficient .00435, we multiply it by $\sqrt{29.63}$ to bring it to one absolute atmosphere, we divide it by 60 to bring it to seconds, and finally we divide by ⊙, and we get as the effect, with heavy end up, .0001256 T_u. To find the effect with heavy end down, we simply multiply by $\frac{h_u}{h_d}$, which gives .0000548 T_d. When the bells are off, $\frac{7}{8}$ of these values are to be taken.

At excessively low pressures the whole theory of atmospheric viscosity fails, because the fundamental hypotheses are then violated; and, therefore, the real effect of viscosity at $\frac{1}{4}$ inch pressure will probably be somewhat smaller than calculation would make it.

Experiments have been made at Hoboken on the Geneva support, in order to determine the effect of atmospheric pressure *à posteriori*. A series of experiments were made in September, 1877, with heavy end down, and another in December, 1877, with heavy end up. The duration of each experiment was generally long, and the agreement of the results is all that could be expected. These observations were made by Mr. Farquhar. The temperature, during the September experiments, was about 20° C.; that during the December experiments was about 10° C. They have been corrected so as to bring them exactly to these temperatures. The results of these experi-

ments are exhibited on illustrations Nos. 37*a* and 37*b*. It will be seen that the sidereal time of oscillation, with heavy end down, satisfies the formula

$$\overset{s.}{T_d} = 1.006072 + .00000985\,p + .0000081\,\sqrt{p};$$

and those with heavy end up, the formula

$$T_u = 1.005740 + .00002264\,p + .0000234\,\sqrt{p},$$

where p is the pressure in inches at 15° C.

Taking one absolute atmosphere, or 29.63 inches, as the unit of pressure, and reducing the coefficients to 15° C., we have the general formulæ,

$$\overset{s.}{T_d} = 1.006027 + .0002969\,\frac{p}{\tau} + .0000442\,\frac{\sqrt{p}}{\sqrt[4]{\tau}},$$

$$T_u = 1.005785 + .0006598\,\frac{p}{\tau} + .0001271\,\frac{\sqrt{p}}{\sqrt[4]{\tau}}.$$

The values which we have obtained *à priori* are

$$T_d = x \qquad + .0002789\,\frac{p}{\tau} + .0000551\,\frac{\sqrt{p}}{\sqrt[4]{\tau}},$$

$$T_u = y \qquad + .0006388\,\frac{p}{\tau} + .0001263\,\frac{\sqrt{p}}{\sqrt[4]{\tau}}.$$

The difference between observation and *à priori* calculation is perhaps not greater than ought to be expected. The values which have been used in the reductions are

$$T_d = x \qquad + .0002917\,\frac{p}{\tau} + .0000512\,\frac{\sqrt{p}}{\sqrt[4]{\tau}},$$

$$T_u = y \qquad + .0006694\,\frac{p}{\tau} + .0001175\,\frac{\sqrt{p}}{\sqrt[4]{\tau}}.$$

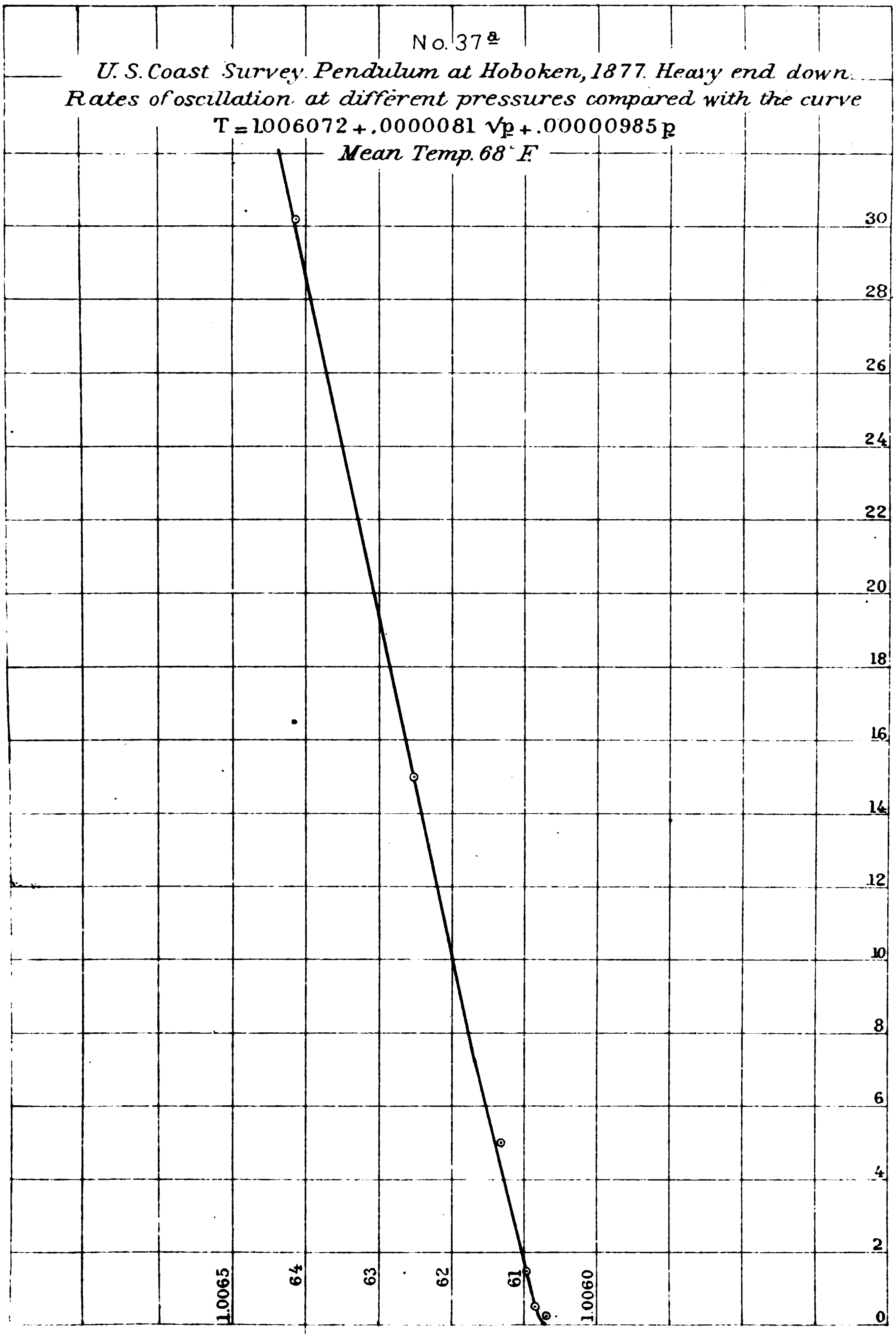
These values were used before the last calculations of the *à priori* values were completed, and it was not thought worth while to change them; but the *à priori* values are preferred.

COEFFICIENT OF EXPANSION.

The coefficient of expansion of the pendulum has been determined, by comparing it directly with a meter obtained from the German Imperial Eichungsamt and there designated as Normal Meter No. 49, and also by assuming it to have the same coefficient as the pendulum-meter, the pendulum-meter having also been compared at different temperatures with No. 49. The coefficient of expansion of No. 49 has been absolutely determined by comparison with meter made for the purpose and marked "U. S. C. S.—C. S. P.—1878.—A." The comparisons have been made

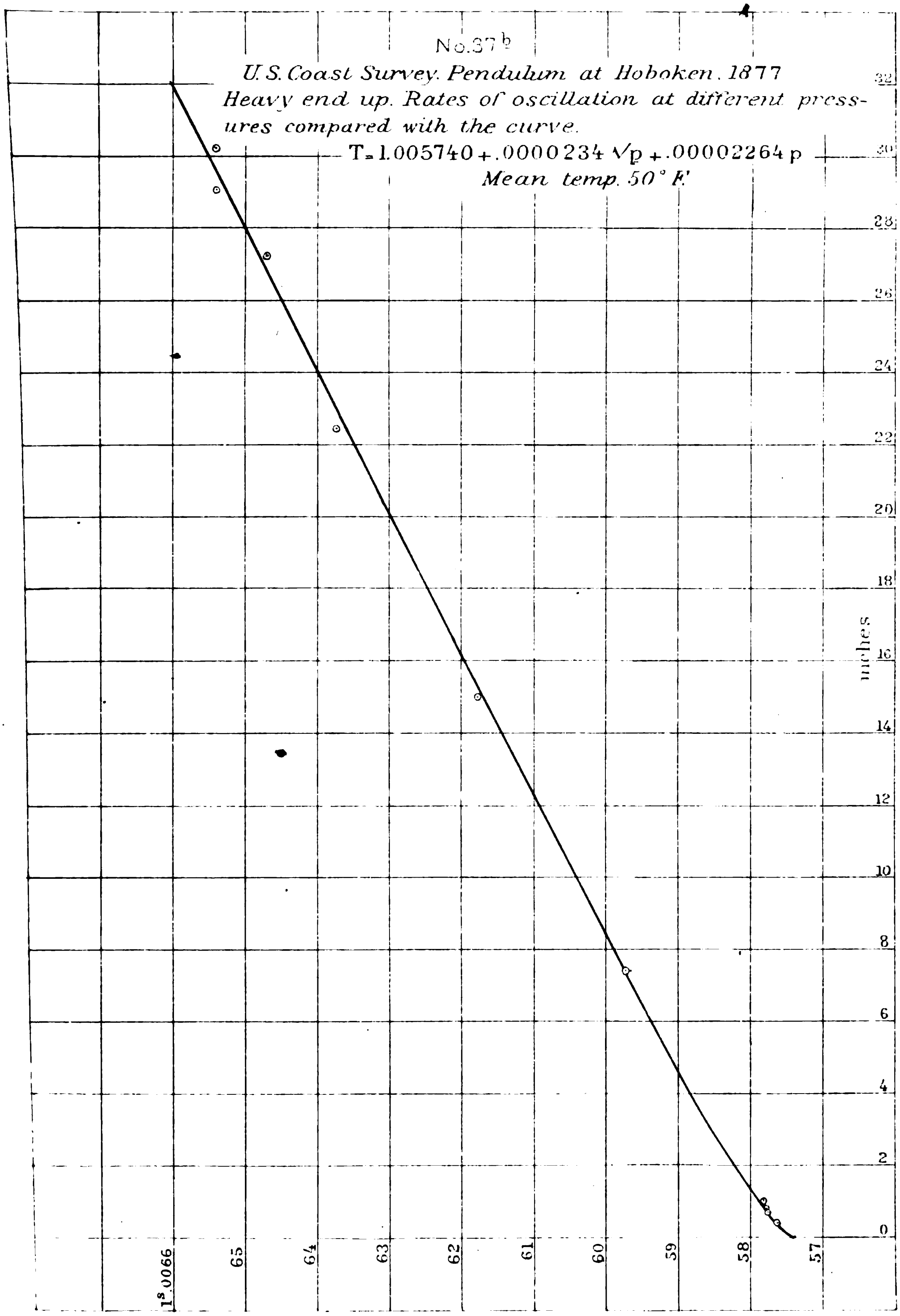
Between No. 49 at 13° and A at 3°
Between No. 49 at 3° and A at 13°
Between No. 49 at 4° and A at 4°
and between No. 49 at 18° and A at 18°

The two meters were compared by means of the vertical comparator belonging to the reversible pendulum. They stood in two vertical brass tubes, 4½ cm. in diameter and 1¼ m. long, polished on the exterior and closed at the bottom by a foot terminating in a conical point. One of them rested in the step designed for the pendulum-meter, and was held at the top in a stirrup, movable upon a screw in such a way as to vary its distance from the microscope. The meter rested at the bottom of the tube in a species of trap, in which it was compressed just sufficiently to hold it in place. At about ¾ m. from the bottom it was lightly held, by springs on its four sides, into a frame which was capable of being moved in any direction, by means of four horizontal screws penetrating the walls of the brass tube. India-rubber washers and nuts kept the screw-holes water-tight. Opposite the lines at the top and bottom of the meter, two windows were inserted in the brass tube, setting into little sashes formed of brass casting. These windows were made of plate-glass, about 3 mm. thick, which was carefully selected with a view to the parallelism of its sides, and placed in the sash in such a way that the slope of the wedge should be horizontal. These glass windows were kept water-tight by rubber washers, having a brass washer over them screwed down by four thumb-



No. 37ª

U. S. Coast Survey Pendulum at Hoboken, 1877. Heavy end down.
Rates of oscillation at different pressures compared with the curve
$T = 1.006072 + .0000081\sqrt{p} + .00000985\,p$
Mean Temp. 68° F.


No. 37 b
U. S. Coast Survey. Pendulum at Hoboken. 1877
Heavy end up. Rates of oscillation at different pressures compared with the curve.
T = 1.005740 + .0000234 √p + .00002264 p
Mean temp. 50° F.
inches
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
1s.0066
65
64
63
62
61
60
59
58
57

screws. At the opposite side of the tube, a little above the middle of the meter, was a third window through which a thermometer placed within the tube could be read. These tubes were furnished with stop-cocks at the bottom, and a rapid current of water was kept running through them during the measures and for at least an hour previous. The comparator, tubes, and meters having been put into perfect adjustment, the tubes were fixed tightly in their places by screws, and remained unmoved during the whole of the experiments. Particular care was taken that they should not turn on their axes, so as to alter in any degree the effect of refraction in the glass windows. The comparator was not fixed, since it was necessarily turned from one meter to the other, and also changed in length by a fraction of a millimeter, when the temperature was changed, a screw being provided for the purpose. The two meters were separated from one another and from the comparator by means of screens about 4 mm. thick, consisting of light wooden frames with tin-plate on the two sides, and loosely filled in the interior with cotton batting.

The coefficient of expansion of No. 49 is checked by comparisons at various temperatures with the platinum meter of the German Eichungsamt; for the coefficient of expansion of platinum has been accurately determined by Fizeau.

As one of the most prominent living metrologists has stated his conviction that the coefficient of expansion of a meter may be expected to be different in the vertical and horizontal positions it is proper to examine this question. Let the meter be of brass and let its cross-section be 2 $(\mathrm{cm})^2$. The solid contents of this meter will be 200 $(\mathrm{cm})^3$ and its mass may be taken at 1680 gr. The modulus of elasticity of brass, according to Wertheim, is $9 \times 10^{11} \frac{\mathrm{gr.}\,(\mathrm{s})^2}{(\mathrm{cm})}$. This is not the same at all temperatures, however, and judging from the analogy of copper we may suppose it $\frac{1}{11}$ part smaller at 100° than at 0°. If the meter be set up on end the mean pressure of its own weight is $\frac{1}{4}\, 1680 \times 981 \frac{\mathrm{gr.\ s}^2}{\mathrm{cm.}}$. Let the expansion from 0° to 100° be x' in the horizontal position. Let the length of the bar in the horizontal position at 0° C. be 1 meter. Let it be heated to 100° C. in this position; its length will then be $1 + x'$. Let it next be placed in the vertical position; then, its length will be reduced by its weight to

$$(1 + x')\,(1 - \tfrac{11}{10} \times 420 \times 109 \times 10^{-11}).$$

Let it, next, be cooled to 0° and its length will be

$$(1 + x')\,(1 - \tfrac{11}{10} \times 420 \times 109 \times 10^{-11})\,(1 - x).$$

Let it, next, be brought to the horizontal position, and its length will be

$$(1 + x')\,(1 - \tfrac{11}{10} \times 420 \times 109 \times 10^{-11})\,(1 - x)\,(1 + 420 \times 109 \times 10^{-11}).$$

But it is, now, in the original condition so that this length = 1. This gives the equation

$$x' - x = 42 \times 109 \times 10^{-11},$$

a quantity too small to be detected.

The following is a summary of the results of the comparisons between meters A and 49:

Temp. of 49.	Temp. of A.	A — 49.
°	°	μ.
+13	+ 3	+130.5
3	13	−247.3
4	4	− 58.8
18	18	− 57.7

These results are all satisfied to the last place of decimals by taking the coefficient of expansion

$$\text{of A} = \overset{\mu.}{18.95} \text{ for } 1^\circ \text{ C.}$$
$$\text{of } 49 = 18.83 \text{ for } 1^\circ \text{ C., and}$$
$$\text{A} - 49 \text{ at } 0^\circ \text{ C} = -59.3$$

The comparisons are given in detail in the subjoined table.

UNITED STATES COAST SURVEY.—COMPARISONS OF METERS "A" AND "49."

[t_A temperature Centigrade of A. t_{49} temperature of 49.]

Date.	Time.	$\frac{1}{2}(t_A+t_{49})$	$\frac{1}{2}(t_A-t_{49})$	A − 49	$\frac{1}{2}\Sigma$ to 8°	$\frac{1}{2}\Delta$ to +5°	Corrected A − 49	Diff. from mean (+130.5)
	h. m.	°	°	μ.	μ.	μ.	μ.	
May 14	....	7 57	+5.32	+138.7	0.0	−12.1	+126.6	−3.9
14	0 40	8.54	+4.68	+120.0	0.0	+12.1	+132.1	+1.6
14	....	8.65	+4.80	+123.6	−0.1	+ 7.6	+131.1	+0.6
14	....	8.30	+5.25	+142.1	0.0	− 9.5	+132.6	+2.1
14	....	8.36	+5.24	+140.8	0.0	− 9.1	+131.7	+1.2
14	....	8.38	+5.24	+141.5	0.0	− 9.1	+132.4	+1.9
14	....	8.79	+4.99	+132.5	−0.1	+ 0.4	+132.8	+2.3
14	....	8.91	+5.11	+137.8	−0.1	− 4.2	+133.5	+3.0
15	....	9.11	+4.33	+105.5	−0.1	+25.3	+130.7	+0.2
15	....	8.72	+4.80	+121.1	−0.1	+ 7.6	+128.6	−1.9
15	....	8.22	+5.30	+139.9	0.0	−11.3	+128.6	−1.9
15	....	8.26	+5.29	+139.8	0.0	−11.0	+128.8	−1.7
15	....	8.40	+5.10	+133.5	0.0	− 3.8	+129.7	−0.8
15	....	8.50	+5.05	+131.6	0.0	− 1.9	+129.7	−0.8
15	....	8.61	+5.06	+133.4	−0.1	− 2.3	+131.0	+0.5
15	9 00	8.94	+4.84	+121.8	−0.1	+ 6.0	+127.7	−2.8
					$\frac{1}{2}\Sigma$ to 8°	$\frac{1}{2}\Delta$ to −5°		(−247.3)
16	21 00	7.90	−4.16	−216.6	0.0	−31.8	−248.4	−1.1
16	22 00	7.28	−4.95	−245.3	+0.1	− 1.9	−247.1	+0.2
16	23 00	7.42	−5.02	−247.7	+0.1	+ 0.8	−246.8	+0.5
16	....	7.58	−5.09	−251.4	0.0	+ 3.4	−248.0	−0.7
16	0 30	7.72	−4.99	−247.9	0.0	− 0.4	−248.3	−1.0
16	3 30	8.94	−5.14	−251.5	−0.1	+ 5.3	−246.3	+1.0
16	....	8.92	−5.22	−257.4	−0.1	+ 8.3	−249.2	−1.9
16	....	8.85	−5.32	−258.4	−0.1	+12.1	−246.4	+0.9
16	8 30	9.84	−4.73	−235.2	−0.2	−10.2	−245.6	+1.7
					$\frac{1}{2}\Sigma$ to 4°	$\frac{1}{2}\Delta$ to 0°		(−58.8)
17	22 00	3.45	+0.02	− 59.2	+0.1	− 0.8	− 59.9	−1.1
17	22 30	4.04	−0.04	− 62.1	0.0	+ 1.5	− 60.6	−1.8
17	23 30	4.58	+0.04	− 55.5	−0.1	− 1.5	− 57.1	+1.7
17	....	6.00	0.00	− 61.0	−0.2	0.0	− 61.2	−2.4
17	....	6.46	+0.03	− 58.1	−0.3	− 1.1	− 59.5	−0.7
18	....	4.06	−0.02	− 58.5	0.0	+ 0.8	− 57.7	+1.1
18	3 15	4.05	−0.01	− 61.5	0.0	+ 0.4	− 61.1	−2.3
18	3 30	3.96	0.00	− 57.8	0.0	0.0	− 57.8	+1.0
18	3 50	4.04	−0.02	− 56.4	0.0	+ 0.8	− 55.6	+3.2
18	4 08	4.14	0.00	− 58.2	0.0	0.0	− 58.2	+0.6
18	4 20	4.22	0.00	− 60.4	0.0	0.0	− 60.4	−1.6
18	4 50	4.34	+0.02	− 56.9	0.0	− 0.8	− 57.7	+1.1
18	5 15	4.46	0.00	− 57.4	0.0	0.0	− 57.4	+1.4
					$\frac{1}{2}\Sigma$ to 18°	$\frac{1}{2}\Delta$ to 0°		(−57.2)
20	21 30	18.19	0.00	− 57.1	0.0	0.0	− 57.1	+0.1
20	21 45	18.26	+0.01	− 57.0	0.0	−0.4	− 57.4	−0.2
20	22 00	18.32	0.00	− 56.8	0.0	0.0	− 56.8	+0.4
20	22 20	18.45	0.00	− 57.4	0.0	0.0	− 57.4	−0.2
20	23 30	18.65	+0.01	− 55.3	−0.1	−0.4	− 55.8	+1.4
20	23 45	18.70	0.00	− 57.2	−0.1	0.0	− 57.3	−0.1
20	1 45	18.72	+0.01	− 56.8	−0.1	−0.4	− 57.3	−0.1
20	2 15	18.76	+0.02	− 56.1	−0.1	−0.8	− 57.0	+0.2
20	3 50	18.75	+0.03	− 57.1	−0.1	−1.1	− 58.3	−1.1

The comparisons made between the German Normal Meter No. 49 and the platinum meter of the Eichungsamt give

$$\text{No. } 49 - \text{Pl. M} = -24^{\mu}.4 + 10^{\mu}.09\ \tau_1,$$

where τ_1 denotes the temperature Centigrade; and the following table shows the agreement of this formula with the observations communicated by Professor Förster:

τ_1	No. 49 — Pl. M.	Same, calc.
°	μ	μ
+ 3.25	+ 8.2	+ 8.4
6.28	39.2	39.0
23.55	213.1	213.2

Fizeau's coefficient of expansion for platinum is at 0° C., $8^{\mu}.68$ for 1° Centigrade; at 11° C., the mean temperature of these comparisons, this coefficient becomes $8^{\mu}.72$. Hence the coefficient of expansion for Meter No. 49, as deducted from these comparisons, is $18^{\mu}.81$. This agrees very well with the absolute determination above given, which may therefore be adopted.

The comparisons between the pendulum-meter and No. 49 are not very satisfactory in their results, but they show that the coefficient of expansion of the former is certainly the smaller of the two. The following table shows the observed results as compared with the formula

$$\text{U. S. Pendulum-Meter} - \text{No. } 49 = -13^{\mu}.3 - 0^{\mu}.448\ \tau_1.$$

Date. 1878.	τ_1	U. S.— No. 49.	Same, calc.	Calc. — Obs.
	°	μ	μ	μ
March 20	20.25	− 25.0	− 22.4	+ 2.6
21	19.68	21.2	22.1	− 0.9
22	20.14	22.9	22.3	+ 0.6
23	19.93	22.0	22.2	− 0.2
24	16.84	19.1	20.8	− 1.7
25	13.37	19.5	19.3	+ 0.2
26	8.11	17.1	16.9	+ 0.2
26	14.07	18.5	19.6	+ 0.9
27	10.58	16.6	18.0	− 1.4

The pendulum itself, compared with No. 49 at 35° C., and at 10° C., gives the following equation:

$$\text{Pendulum} - \text{No. } 49 = -191^{\mu}.5 - 0^{\mu}.67\ \tau_1.$$

The coefficient of expansion of the pendulum, therefore, as given by these comparisons, is

$$18^{\mu}.83 - 0^{\mu}.67 = 18^{\mu}.16.$$

The coefficient of the pendulum-meter, just found, is $18^{\mu}.83 - 0^{\mu}.45 = 18^{\mu}.38$. The mean of these two values is $18^{\mu}.27$.

The coefficient of expansion of the pendulum was also determined from its rate of oscillation at different temperatures, a special series of experiments at high temperatures being taken for the purpose. The results are given below:

	HEAVY END DOWN.		HEAVY END UP.	
	τ_1	T_d	τ_1	T_u
	°	s.	°	s.
Observed values	35.8 19.4	1.006537 1.006400	36.3 10.2	1.006719 1.006536
Differences	16.4	.000137	26.1	.000183
Correction for atmospheric temperature	......	+ 16	......	+ 58
		.000153		.000241
Effect for 1° C	......	.0000093	......	.0000092

These give as the coefficient of expansion—

From oscillations with heavy end down	$18^{\mu}.5$
From oscillations with heavy end up	18 .3

The value 18 .3 has been used in the reductions.

CORRECTIONS FOR THE WEARING DOWN AND ROUNDING OFF OF THE KNIFE-EDGES.

If 5 kilogrammes' weight be put upon an absolutely sharp knife-edge of steel hardened in oil and having a bearing length of 2 centimeters, the steel edge will be crushed until the breadth of the bearing surface is 1 micron. Accordingly, from the very beginning, a knife-edge will wear down and round off. The wearing down and the blunting will have very different effects upon the period of oscillation.

The removal of the point of support of a pendulum from its center of mass, will have an effect which is readily calculated, thus:

$$\mathrm{d}\,T^2 = \mathrm{d}\,.\frac{\circledS^2}{g}\left(\frac{\gamma^2}{h} + h\right) = \frac{\circledS^2}{g}\left(-\frac{\gamma^2}{h} + h\right)\frac{\mathrm{d}\,h}{h}.$$

For a reversible pendulum,

$$\gamma^2 = h_d\, h_u.$$

Hence, we have,

$$\mathrm{d}\,T_d^{\,2} = T_d^{\,2}\,\frac{h_d - h_u}{h_d + h_u}\,.\,\frac{\mathrm{d}\,h_d}{h_d}$$

$$\mathrm{d}\,T_u^{\,2} = -\,T_u^{\,2}\,\frac{h_d - h_u}{h_d + h_u}\,:\,\frac{\mathrm{d}\,h_u}{h_u}$$

If a pendulum rolls upon a cylindrical surface of radius ρ, the instantaneous axis of rotation is the instantaneous line of contact; and a velocity of rotation about this axis is equivalent to the same velocity of rotation about the line of contact in the equilibrium position of the pendulum combined with such a translation velocity along the length of the pendulum as is necessary to fix the instantaneous axis; this is $2\rho\sin\frac{1}{2}\varphi\,.\,\frac{\mathrm{d}\varphi}{\mathrm{d}\,t}$. It follows that the amount by which the *vis viva* of the pendulum is affected by a cylindricity of the knife-edge is of the order of $\rho^2\,\varphi^2$ and may consequently be neglected. The moment of gravity is, however, obviously the same as if the axis of the cylinder were the axis of rotation, that is, it is multiplied by $\left(1 + \frac{\rho}{h}\right)$. Hence we have

$$\delta\, T^2 = -\,T^2\,\frac{\rho}{h}.$$

If the section is not circular, then obviously some sort of a mean radius of curvature must replace ρ. If the section is flatter than a circle, that is, if the lower parts in repose have the greater radii of curvature, then the mean radius, and consequently the effect on the period of oscillation, will be greater for small arcs than for large ones; while if the section is somewhat pointed downwards the reverse will be the case.

We know too little of the laws of crushing and grinding to be able to calculate the radius of curvature from the amount worn off. In fact, the ratio would probably depend on the hardness of the material. Neither can the radius be measured directly with any accuracy. But it may obviously be very large. When the pendulum is first brought down to rest on the edge, why may not the blunted surface be nearly flat? If it were so, the small oscillation through 4° or 5° could not round the edges enough to make the ratio of the radius to the wearing down at all small. Under these circumstances it is a question deserving consideration and experimental examination whether

it would not be better to substitute for knife-edges cylinders of measurable diameter—say of 5 millimeters.

Our own experiments always began with a half-amplitude of 2° and ended with a half-amplitude of ½°; but the time of intermediate transits of the pendulum across the vertical was observed when the half-amplitude reached 1½° and 1°. The intervals of time between the 2° and 1½° observations were too short to found any conclusions upon; but if we compare the mean period of oscillation while the arc is descending from 2° to 1° with the mean period while the arc is descending from 1° to ½°, we do not find, after the usual correction for arc, any decided difference between them. This is shown in the following table:

Station.	Position of heavy end.	PERIODS OF OSCILLATION. (Corrected for arc, pressure, temperature, and rate of time-keeper.)		DIFFERENCE.	
		Arc, 2° to 1°.	Arc, 1° to ½°.	Heavy end down.	Heavy end up.
		s.	s.		
Paris	Down	1.006053	1.006050	−3	
	Up	1.006195	1.006198		+3
Berlin	Down	1.005901	1.005897	−4	
	Up	1.006028	1.006033		+5
Kew	Down	1.005931	1.005930	−1	
	Up	1.006054	1.006056		+2
Hoboken	Down	1.006355	1.006358	+3	
	Up	1.006550	1.006548		−2

There are, it is true, slight indications here of a correction varying with the amplitude and different for the Repsold support, used at the European stations, and for the Geneva support, used at Hoboken; but nothing can be concluded with certainty.

The measures of length show, in each case, an increase in the distance between the knife-edges from station to station. Thus we have—

		μ
Increase of length from	Paris to Berlin	4.1
	Berlin to Kew	3.1
	Kew to Hoboken	8.9

This increase cannot have been in any degree due to the wearing down of the knife-edges, for the reason that the measures were made between the centers of the edges, which portions do not bear upon the support and appear, even now, nearly sharp. The increase is most probably due to accumulations of cocoa-butter, etc., under the steel of the knives where they bear on the brass. The effect is, therefore, that of a wearing down without any blunting.

The only indication which we have as to the actual wearing down and blunting is derived from the difference between the periods of oscillation with heavy end down and up. The difference will be

$$C - \frac{20}{21}\,\delta h - \frac{2}{21}\,\rho.$$

It is highly objectionable to infer the values of δh and ρ from the numbers which are to be used to determine the force of gravity. It is fortunate. therefore, that the whole of the wearing and blunting which it is necessary to take account of for the European stations, took place, all at once, at Berlin, after just one-half of the work there had been done. The change is therefore deducible from the Berlin observations alone, and that from the difference of the first half and last half of

them, independently of the mean of the whole. The differences of T, with heavy end up and heavy end down, at Berlin, are as follow:

	First four days.	Last four days.
	s.	*s.*
	0.000153	0.000123
	0.000136	0.000126
	0.000131	0.000131
	0.000140	0.000123
Mean......	0.000140	0.000126

When these means are corrected for the measured change of length from that at Paris, they become

0.000142	0.000128

Now, the same difference at Paris is—

	s.
First four days	0.000144
Second four days	0.000140
Mean	0.000142

which agrees exactly with the first four days at Berlin; and the same difference at Kew, after correction for the measured change of length from Paris, is—

	s.
First four days	0.000128
Second four days	0.000129
Mean	0.000128

which agrees exactly with the last four days at Berlin. We thus find that it is quite unnecessary to take account of any other blunting in Europe than that which took place at that time.* To separate the effects on T_d and T_u, we have

BERLIN.

	T_d	T_u
	s.	*s.*
First days	1.0058980	1.0060378
Last days	1.0058988	1.0060246
Changes	+08	−132

The negatives of half these changes are, therefore, to be applied to the observations at Kew, and only the first 4 days' observations at Berlin are available. The deduced values of the wearing down and of the radius of curvature of the section are

$$\delta h = 11^{\mu}.5 \quad \rho = 32^{\mu}.$$

These results agree well with direct observations of the edges, which have been made under a high-power microscope, with illumination through the objective.

The regular set of observations at Hoboken were made upon the Geneva support, instead of the Repsold support, which had been used before. Now, it is a matter of observation that the edges do not even yet, after all their wearing, rest over their whole length upon the Repsold support, but only near their ends. On the other hand, on the Geneva support, they rest nearer the middle. The consequence is that when the Geneva support was used, quite new and unblunted parts of the edges came into play, so that the edges should have been in the same state as at Paris; and this will be assumed to have been the case, though the differences of the supports in other respects prevent a very close comparison.

* It will be observed that this comparison of the difference of T_d and T_u at different stations could not have been made if the atmospheric corrections had not first been applied.

The two knives cannot be assumed to be alike, either in respect to the distances of the edges from the planes of the bearings of the steel on the brass, or in the figure of the edges; but inasmuch as they are interchanged and equal numbers of experiments made in the two positions, this inequality can have no effect on the final result. But to exhibit the agreement of single days' experiments, the inequality should first be allowed for. In the Paris experiments and the first experiments at Berlin, there was no perceptible difference between them. Thus, we find

Excess of time on oscillation on knife 1 *over that on knife* 2.

	Heavy end down.	Heavy end up.
	s.	*s.*
Paris	+0.000002	−0.000008
Berlin (first days)	−0.000002	+0.000014
Weighted mean	+0.000001	+0.000001

But for the last days at Berlin, and for Kew, the difference is quite perceptible.

Excess of time of oscillation on knife 1 *over that on knife* 2.

	s.	*s.*
Berlin (last days)	+0.000006	+0.000010
Kew	+0.000004	+0.000005
Weighted mean	+0.000004	+0.000006

Half these amounts will be applied with their appropriate signs in exhibiting the results of single days. At Hoboken this correction disappears again.

CORRECTION FOR THE SLIP OF THE KNIFE-EDGES.

There is, according to Bessel, another effect due the knife-edges, which has reverse signs, with heavy end up and down, and which is consequently not eliminated in the formula for the reversible pendulum, although it is eliminated when the periods of oscillation are combined by the formula suitable in considering it as two invariable pendulums, to wit:

$$T = \frac{T_d h_d + T_u h_u}{h_d + h_u}.$$

This action may be termed the slip of the knife-edge, as it is supposed to be due to a motion which the knife is compelled to make, and which no elastic force resists.

In order to detect the existence of such an effect, a stiff steel knitting-needle was slipped through the notch in the support of the knife-edge, while the pendulum was in position, and was then brought up into contact with the edge by copper wires fastened to its extremities and also to a frame mounted on the head of the pendulum-support. These wires had considerable length, so that the knitting-needle was free to move in the direction of its length, while the friction on the knife-edge was very great, so that if the edge had any slip the knitting-needle must oscillate in the direction of its length. In order to observe any such motion a bit of convex spectacle-lens of long focus was attached to one end of the needle, and a plane piece of glass was brought up nearly against it; with the aid of a lamp burning alcohol with salt, Newton's rings were produced and were observed with a microscope, according to the well-known method of Fizeau. The result of this experiment was that, with the largest oscillation of the pendulum, not the least slip could be detected in this way, so that it seemed that there could be no slip as great as $\frac{1}{20}$ of the wave-length of the D line; that is, none amounting to $\frac{1}{20}$ of $\frac{6}{10}$ of a micron.

As this result was unexpected, not to say surprising, the apparatus was critically studied; but it seemed impossible that any slip should occur at the point of contact of the edge with the needle without showing itself in this way.

It might be, however, that, instead of a true slip, the edge was turned at each oscillation, so as to produce a motion similar to a slip; for such an effect would not be detected by our experiment.

CORRECTION FOR SHORTER LENGTH WITH HEAVY END UP.

When the heavy end is down the pendulum is stretched by a greater length. Calculating from the known coefficient of elasticity of brass, this stretching is found to amount to $1^{\mu}.0$. In the measures of length this amount has accordingly uniformly been added to the length with heavy end up. There is, therefore, a correction of $+10$ in the seventh place to be added to T^2_u to bring it to what it would be if the pendulum were as long as the reduced measures make it.

THE CORRECTION FOR THE FLEXURE OF THE SUPPORT.

The work upon this correction has been so extensive that it is thought best to reserve the full account of it for a separate paper. It has been shown by the writer that if a horizontal force equal to the weight of the unit of mass deflects the point of support through a distance S, and if M is the mass of the pendulum, h the distance of the center of mass from the point of support, and l the length of the corresponding simple pendulum, then the effect of the swaying of the stand with the movement of the pendulum is to lengthen the square of the period of oscillation by $T^2 M \frac{S h}{l^2}$; and the effect on λ the length of the seconds' pendulum found with the reversible pendulum is to make it too short by $M S \frac{\lambda}{l}$. This supposes the support to be perfectly elastic, and without any difference between statical and dynamical elasticity.

The quantity S has been found from a long series of experiments to be equal to $0^{mm}.0340$ for the Repsold support. At Paris a larger value ($0^{mm}.0371$) was found, but the larger value has not been used in the reductions. Possibly it should have been used.

When the Repsold tripod rests on a flexible support of any kind the value of S is of course increased. At Hoboken there was no such increase. It is not believed that this increase was a considerable quantity at either Berlin or Kew, but the first occasion will be seized of measuring it. At Paris it may account for the larger value of S there obtained. At Geneva the pendulum was swung on a wooden support. The effect of which may be estimated as follows: Professor Plantamour finds that the correction $M S \frac{\lambda}{l}$ for his pendulum swinging on this wooden support at Geneva was $0^{mm}.1724$, and at Berlin on a pier similar to that on which the Coast Survey pendulum tripod rested the same correction was $0^{mm}.1357$. The difference, or $0^{mm}.036$, may be taken as the effect of the flexure of the wooden stand. Now, the following are the data concerned, which differ for his experiments and for ours:

	Swiss pendulum.	American pendulum.
Mass of pendulum	3050 gr.	6308 gr.
Ratio of seconds' pendulum to length between knives	1.77	1
Height of edge above feet	1 m.	1.3 m.

It follows that the effect of the flexibility of the wooden table would be greater for the Coast Survey pendulum in the ratio of $\frac{6308}{3050} \times \frac{1}{1.77} \times (-1.3) = 1.98$; so that the correction for our pendulum swinging on this table will be $0^{mm}.217 + 0^{mm}.071 = 0^{mm}.287$.

For the Geneva support, set up as it was at Hoboken, the total value of S (for metallic part and piers) was found to be $0^{mm}.00405$. For the stiffest support the total value was $0^{mm}.0031$.

M. Plantamour has observed a phenomenon which he supposes to be due to the pendulum-support not yielding so much under the oscillations of the pendulum as the amount calculated from the statical flexure. For a wooden support the hypothesis is certainly admissible. For a metallic support it should only be admitted with extreme caution. Elaborate experiments at Hoboken seem to show the ratio of statical to dynamical flexure to be as 263 to 257. Whether or not, supposing the difference to exist, the statical or dynamical flexure ought to be used in calculating the correction has not been made out by any mathematical analysis. In the corrections applied in this research the statical value has been used.

LENGTH OF THE PENDULUM.

The distance between the knife-edges of the pendulum depends upon the comparisons shown in the following scheme:

Pendulum.

United States Pendulum Meter.

German Pendulum Meter. German Normal Meter No. 49.

German Normal Meter No. 1605. German Platinum Meter.

The comparisons between the German meters were made in the Imperial Eichungsamt at Berlin, and the results communicated by Professor Förster. In addition, Bruhns's Report on Professor Albrecht's Pendulum Experiments gives a comparison between the German pendulum meter and what he calls "Der Normalmeter der Eichungskommission," also made at the Eichungsamt in Berlin; but as it is impossible to tell specifically what he means by this expression, as the German Eichungskommission states that it never had any intention of establishing an independent standard of its own, and as the result given by Bruhns disagrees entirely with the results of other comparisons, this comparison must be excluded. It is possible that the German pendulum meter received some injury between the time of Bruhns's comparison and that with No. 1605, communicated by Professor Förster. If such was the case, the injury probably occurred before the first comparison between it and the United States pendulum meter, for, as then noticed, when the position had been adjusted by means of the spirit-level, the scales at the top and bottom of the tube were not in the same vertical line.

One set of comparisons between the two pendulum meters was made in 1875, and another in 1877, by means of the vertical comparator belonging to the United States apparatus.

Meter No. 49 in its comparison with the pendulum meter, and with the pendulum, was supported at the bottom on a foot made for the purpose.

Comparisons between the pendulum and pendulum meter were made before and after every swing, at first; but at Kew and Hoboken it was thought sufficient to make one comparison before and one after each change of knife-edges, in addition to those made at the beginning and end of the series.

The order in which micrometrical readings were taken in these comparisons was as follows:

1. Metallic thermometer.
2. Meter below.
3. Meter above.
4. Pendulum above, bright edge.
5. Pendulum above, dark edge.
6. Pendulum below, bright edge.
7. Pendulum below, dark edge.
8. Meter above.
9. Meter below.
10. Metallic thermometer.

The method of adjustment of the stand and comparator has been already described in the first part of this report, under the head of "Instruments." The length of the comparator was made nearly a mean between those of the pendulum and pendulum-meter, and its middle brought to a level with the middle of the pendulum. The middle of the meter was then raised to the same height, its foot moved until the vertical lines at its two ends were simultaneously in coincidence with the vertical webs of the two microscopes, and both ends brought into perfect focus. The adjustment of the comparator, once made, was never disturbed; that of the focus on the standard was often repeated.

The lines of the metallic thermometer observed on were the three nearest the three lines one-tenth of a millimeter apart at the beginning of the meter-scale. Care was taken, however, to observe on the same three lines in every comparison at the same station. When the metallic thermometer was below, the reading of the meter taken in conjunction with it was not repeated; when it was above, at Berlin and Paris, the meter-scale above was read twice. At Kew, the meter-scale below was read first and last, and the scale above with the thermometer but once. A calibrated mercurial thermometer was read to hundredths of a degree Centigrade before and after each observation of the metallic thermometer. The corrections of this thermometor will be given in another place. The mark at the end of one meter, and the two lines at the distance of one hundredth of a centimeter on each side, were observed on at Paris and Berlin; at Kew and Hoboken the lines observed on were those at distances of $99^{cm}.97$, $99^{cm}.98$, and $99^{cm}.99$ from the zero of the scale. Three readings on each line of the meter-scale, or nine in all, were taken at Paris; two readings on each line at Berlin and Kew, and but one at Hoboken, it being found advisable to finish the comparison as quickly as possible, that the apparatus might not be affected by the heat of the body. In the readings on the pendulum, the method followed at Geneva was used at all other stations. The order given above, of observing on edge bright and edge dark, was not at first strictly observed.

In reducing observations of length, account must be taken of the value of a revolution of the micrometer-screw, of the distance between the lines on the meter-scales (if the same ones were not always observed on), and of the varying compression of the scales compared when they supported varying weights.

In calculating the last-mentioned allowance, the coefficient of elasticity of brass given by Wertheim, namely,

$$927100000$$

for one gramme of weight supported and one square cm. of cross-section, was used.

Measures of the pendulum give as the cross-section of its tube $2.35(\mathrm{cm})^2$. The additional weight carried with heavy end down is 2095g; hence the pendulum is then longer by

$$\frac{2095}{2.35 \times 927100000} = 1^{\mu}.0.$$

Taking the same cross-section for the tube of the pendulum meter, and the weight of the metallic thermometer equal to that given by Bruhns for the thermometer of the German meter, 2213g, its compression, when the thermometer is above, is $1^{\mu}.0$.

The cross-section of meter No. 49 is $1.80(\mathrm{cm})^2$ and half its weight 757g; hence it is longer when measured horizontally than when measured vertically by $0^{\mu}.5$.

ON THE LENGTHS OF VARIOUS MICROMETRIC SCALES EMPLOYED IN THIS RESEARCH.

1. *The United States glass decimeter-scale of centimeters.*—This scale is upon a piece of glass 0.29 cm. thick and roughly cut into a rectangular shape of 14.3 cm. by 5.3 cm. The lines are about 0.34 cm. long and are inclosed between two longitudinal lines which run the whole length of the plate. Lines 0, 5, 10 are longer than the others. The lines are etched, are 20 microns in thickness, and are excessively bad. They are either filled or stained by the etching acid, but the filling (or whichever sort it be) is all on one side.

I have applied to Assistant Hilgard, by whom this scale was made, for information in regard to its corrections. Professor Hilgard replies that the decimeter is correct to $\frac{1}{100000}$ part, but he does not state at what temperature.

The different centimeters of this scale have been compared together by Assistant C. A. Schott. I copy the following from a duplicate record found in the archives of the Coast Survey:

FEBRUARY 21, 1872.

Adjusted micrometer and direction of scale, measured with lower screw,* in order to obtain measures on the same part of the screw for the whole range of the scale:

Scale, 0 to 1.
Lower guide-line, upper screw 80.202 or A.
Upper 73.73

Set upper screw to.......... 76.96
Temperature, 73°.

0.	1.
74.507	55.581
516	583
516	583
521	593
516	588
513	585
510	582
514	588
508	583
508	584
Mean.. 74.513	55.585
Difference 18.928	

1 to 2.
Upper scale.................. 80.33
Lower 73.85

Middle 77.09
Temperature, 73°.8.

1.	2.
74.431	55.506
429	498
428	494
432	500
430	498
429	500
429	500
430	499
429	496
431	498
Mean.. 74.430	55.499
Difference 18.931	

2 to 3.
Upper scale................ 80.34
Lower 73.84

77.09
Temperature, 73°.5.

2.	3.
74.604	55.679
610	686
604	682
602	680
604	679
606	680
606	679
602	678
606	675
601	677
Mean.. 74.605	55.680
Difference 18.925	

3 to 4.
Upper scale................. 80.24
Lower 73.76

77.00
Temperature, 73°.5.

3.	4.
74.255	55.322
257	317
259	327
266	320
264	322
266	318
260	322
261	326
262	322
Mean.. 74.261	55.321
Difference 18.940	

* Called O formerly.

4 to 5.

Upper scale	79.83
Lower scale	73.42
	76.63

Temperature, 73°.5.

	4.	5.
	74.502	55.556
	495	556
	493	550
	490	557
	497	558
	494	561
	493	558
	497	554
	497	557
	493	556
Mean..	74.495	55.556
Difference	18.939	

5 to 6.

Upper scale	79.80
Lower scale	73.34
	76.57

Temperature, 73°.3.

	5.	6.
	74.577	55.682
	575	683
	581	683
	577	686
	578	685
	577	686
	576	678
	576	679
	578	679
	576	678
Mean..	74.577	55.682
Difference	18.895	

6 to 7.

Upper scale	79.79
Lower scale	73.32
	76.56

Temperature, 73°.4.

	6.	7.
	74.425	55.488
	424	484
	422	488
	424	486
	425	490
	426	485
	422	480
	426	484
	426	489
	427	483
Mean..	74.425	55.486
Difference	18.939	

7 to 8.

Upper scale	79.79
Lower scale	73.33
	76.56

Temperature, 73°.4.

	7.	8.
	74.498	55.578
	494	575
	496	576
	498	578
	502	571
	499	572
	496	579
	496	580
	498	577
	499	585
Mean..	74.498	55.577
Difference	18.921	

8 to 9.

Upper scale	79.78
Lower scale	73.32
	76.55

Temperature, 73°.0.

	8.	9.
	74.424	55.498
	423	494
	421	493
	424	492
	420	492
	421	492
	421	496
	420	497
	426	491
	424	496
Mean	74.422	55.494
Difference	18.928	

9 to 10.

Upper scale	79.78
Lower scale	73.30
	76.54

Temperature, 73°.5.

	9.	10.
	74.466	55.547
	458	545
	458	543
	463	547
	468	550
	458	547
	459	549
	462	549
	463	551
	463	544
Mean	74.462	55.547
Difference	18.915	

Repetition of measure 5 to 6.

Upper scale	79.77
Lower scale	73.15
	76.46

Temperature, 73°.8.

	5.	6.
	74.474	55.577
	474	575
	468	574
	472	572
	475	572
	476	573
	477	576
	474	576
	475	578
	469	573
Mean	74.473	55.575
Difference	18.898	
First difference	18.895	
Mean	18.897	

The probable errors of these measures, as calculated from the sums of the residuals, and from the sums of their squares, are shown in the following table:

Line.	Probable error of one pointing in $\frac{1}{1000}$s of rev.		
	From [Δ]	From [Δ^2]	Mean.
0	2.4	3.1	2.8
1	2.5	2.5	2.5
1	1.0	0.8	0.9
2	1.9	2.0	2.0
2	1.9	1.8	1.8
3	1.9	2.0	2.0
3	2.8	2.5	2.6
4	2.0	2.2	2.1
4	2.2	2.2	2.2
5	1.7	1.9	1.8
5	1.1	1.2	1.2
5	2.2	2.0	2.1
6	2.4	2.2	2.3
6	1.2	1.2	1.2
6	1.6	1.5	1.5
7	2.2	2.1	2.1
7	1.4	1.5	1.5
8	2.6	2.7	2.7
8	1.6	1.4	1.5
9	1.9	1.7	1.8
9	2.9	2.6	2.7
10	1.8	1.8	1.8
Mean...	1.96	1.95	1.95

It appears from this that the probable error of the measure of one centimeter by 10 pointings on each of its limiting lines is only $\pm$ 1.95 $\sqrt{\frac{2}{10}}$ thousandths of a revolution or 0.46 micron. The values of the different centimeters of the scale, according to Mr. Schott's measures, are as follows:

Centimeter.	Length in—	
	Revolutions.	True centimeters.
0 to 1	18.928	1.0001
1 to 2	18.931	1.0003
2 to 3	18.925	0.9999
3 to 4	18.939	1.0007
4 to 5	18.939	1.0007
5 to 6	18.897	0.9985
6 to 7	18.939	1.0007
7 to 8	18.921	0.9997
8 to 9	18.928	1.0001
9 to 10	18.915	0.9994
Mean	18.926	....

2. *Glass centimeter, No.* 1, *and other scales ruled upon Rutherfurd's machine.*—This centimeter was ruled upon the best ruling-machine of L. M. Rutherfurd. It is upon a piece of glass 0.20 cm. thick, 3.5 cm. broad, and 3.6 cm. long. Though used January 16, 1878, it is marked "Jan. 18, 1878, No. 1, $18\frac{329\frac{1}{2}}{360}$ rev." The lines upon this scale are about 2 cm. long and one micron broad. They are filled with black lead and varnished over. The limiting lines of the centimeter are each midway between two bundles of 10 lines each, distant from one another by $\frac{5}{360}$ rev. The limiting lines are distant $\frac{45}{360}$ rev. from the nearest lines of the bundles. The extremities of the limiting lines are marked by crosses roughly cut by hand. The measures are to be made over a longitudinal line, which is marked by crosses at the two ends.

On January 16, 1878, this centimeter was superposed face to face, upon the centimeter 5 to 6 on the upper scale glass decimeter-scale of centimeters. The difference was measured upon a Rutherfurd screw-micrometer.

Beginning of cm.:

Cm. No. 1.	U. S. 5–6.		
r	r		
83.405	83.336		
.406	.334		
.404	.334		
83.405	83.335	Diff.	= r 0.070

End of cm.:

64.495	64.451		
.494	.447		
.491	.449		
64.493	64.449	Diff.	= 0.044

Cm. No. 1 longer than 5–6	0.026
Cm. U. S. 5–6, too short by	0.029
Cm. No. 1 too short by	0.003
Cm. No. 1	= 0.9998 cm.

Repetition of the same comparison.

Beginning of cm.:

Cm. No. 1.	U. S. 5–6.		
r	r		
64.679	64.630		
.681	.634		
.686	.634		
64.682	64.633	Diff.	= r 0.049

End of cm.:

83.596	83.518		
.597	.517		
.595	.516		
83.596	83.517	Diff.	= 0.079

Cm. No: 1 longer than 5–6	0.030
Cm. U. S. 5–6, too short by	0.029
Cm. No. 1 too long by	0.001
Cm. No. 1	= 1.0001
Mean of two comparisons	0.9999

Comparison of Cm. No. 1 with U. S. 3–4.

Beginning of cm.:

	U. S. 3–4.	Cm. No. 1.		
	r	r		
	.476	.433		
	.475	.433		
	.474	.432		
				r
	.475	.433	Diff.	= 0.042
End of cm.:				
	.552	.516		
	.552	.517		
	.553	.518		
	.552	.517	Diff.	= 0.035

Cm. No. 1 shorter than U. S. 3–4	0.007
U. S. 3–4 too long	0.013
Cm. No. 1 too long	0.006
Cm. No. 1	= 1.0003

Repetition of comparison, with low power.

Beginning of cm.:

	U. S. 3–4.	Cm. No. 1.		
	r	r		
	.530	.042		
	.532	.040		
	.532	.040		
				r
	.531	.041	Diff.	= 0.490
End of cm.:				
	.452	.956		
	.452	.958		
	.453	.955		
	.452	.955	Diff.	= 0.496

Cm. No. 1 shorter than U. S. 3–4	0.006
U. S. 3–4 too long	0.013
Cm. No. 1 too long	0.007
Cm. No. 1	= 1.0004
Mean of comparisons with U. S. 3–4	1.0003
Mean of comparisons with U. S. 5–6	.9999
Mean of both cm. No. 1	= 1.0001

On 1878, January 17, measures were made on the same Rutherfurd screw-micrometer, using revolutions 55½ to 150½, of the U. S. 5 centimeters from 0 to 5, the 5 centimeters from 5 to 10, and also five measures of the Cm. No. 1, so as to cover the same part of the screw.

U. S. ½ *decimeter* 5 to 10.

5.	10.	5.	
r.	*r.*	*r.*	
150.180	55.652	150.183	
.181	.653	.184	
.181	.654	.185	
150.181	55.653	150.184	Difference 94.529

U. S. ½ *decimeter* 5 to 0.

5.	0.	5.	
r.	*r.*	*r.*	
150.646	56.054	150.638	
.647	.054	.635	
.645	.054	.635	
150.646	56.054	150.636	Difference 94.587

After a complete readjustment the measures were repeated. "Filar 10" and "Filar 8" signify two different positions of the cross-wire.

U. S. ½ *decimeter* 5 to 10.

Filar 10.

10.	5.	10.	
r.	*r.*	*r.*	
55.663	150.181	55.659	
.666	.180	.662	
.667	.180	.662	
55.665	150.180	55.661	Difference 94.517

Filar 8.

r.	*r.*	*r.*	
56.054	150.574	56.052	
.053	.571	.052	
.053	.572	.051	
56.053	150.572	56.052	Difference 94.519
			Mean 94.518

U. S. ½ *decimeter* 0 to 5.

Filar 10.

0.	5.	0.	
r.	*r.*	*r.*	
55.647	150.231	55.655	
.653	.229	.655	
.656	.228	.657	
55.652	150.229	55.656	Difference 94.575

Filar 8.

r.	*r.*	*r.*	
56.041	150.615	56.044	
.038	.614	.044	
.041	.617	.044	
56.040	150.615	56.044	Difference 94.573
			Mean 94.574

	First measure.	Second measure.	Mean.
	r.	*r.*	*r.*
0 to 5.........	94.587	94.574	94.580
5 to 10..........	94.529	94.518	94.524
Difference	.058	.056	
Diff. in microns..	31	30	

Diff. microns, according to Schott, 33

Cm. No. 1.

	r.		
Beginning....	150.754		*r.*
End	131.841	Diff.	18.913
Beginning....	131.485		
End	112.570	Diff.	18.915
Beginning....	112.684		
End	93.778	Diff.	18.906
Beginning....	93.824		
End	74.913	Diff.	18.911
Beginning....	74.756		
End	55.842	Diff.	18.914

Mean....................	18.9118
Mean of decimeter........	18.9104

	cm.
Length of centimeter...	1.0001
By measures of January 16	1.0001
Concluded value	1.0001

This value has a probable error of less than $\frac{1}{10000}$.

This centimeter is equal to 6809½ teeth of Rutherfurd's machine, and as it is $\frac{1}{10000}$ too long, we conclude that 6809 teeth make a centimeter at ordinary temperatures, say about 18° C.

From an investigation which will be published elsewhere, it has been ascertained that the accidental error of position of a line ruled upon Rutherfurd's machine is only $\pm 0^{\mu}.01$; the periodic error differs greatly on different plates, but never amounts nearly to $0^{\mu}.1$. We, therefore, adopt the following values:

$$1 \text{ mm. of } 681 \text{ teeth} = 1^{mm}.0002$$
$$\tfrac{1}{10} \text{ mm. of } 68 \text{ teeth} = 99^{\mu}.87$$
$$\tfrac{1}{100} \text{ mm. of } 7 \text{ teeth} = 10^{\mu}.28$$

ON THE TENTHS OF MILLIMETERS AT THE ENDS OF THE U. S. C. S. PENDULUM-METER, AND ON THE SCREW-REVOLUTIONS OF THE REPSOLD VERTICAL COMPARATOR.

The U. S. C. S. pendulum-meter is similar to the German pendulum-meter described in the publication of the Royal Prussian Geodetical Institute for 1870. At one end, the meter begins with three lines ruled at distances of 10ths of millimeters. At the other end there is a scale of similar lines. The following tables show the comparison of a part of this scale with a millimeter scale of tenths (No. 3) ruled upon Mr. Rutherfurd's machine.

The figures in parenthesis indicate the order of the pointings.

1878, *February* 4.

GLASS SCALE.

	mm. 0.5		*mm.* 0.4		*mm.* 0.3		*mm.* 0.2		*mm.* 0.1
	r.		*r.*		*r.*		*r.*		*r.*
(1)	0.023	(2)	1.001	(3)	1.987	(4)	2.983	(5)	3.981
(10)	0.017	(9)	1.007	(8)	1.990	(7)	2.986	(6)	3.990
(31)	0.004	(32)	0.999	(33)	1.980	(34)	2.981	(35)	3.969
(40)	0.007	(39)	1.000	(38)	1.976	(37)	2.972	(36)	3.968
	0.013		1.002		1.983		2.980½		3.977

METAL SCALE.

	m.		m.		m.		m.		m.
	1.0002		1.0001		1.0000		0.9999		0.9998
	r.		r.		r.		r.		r.
(11)	$\bar{1}$.988	(12)	0.985	(13)	1.983	(14)	2.973	(15)	3.976
(20)	$\bar{1}$.995	(19)	0.988	(18)	1.978	(17)	2.984	(16)	3.971
(21)	0.000	(22)	0.982	(23)	1.990	(24)	2.986	(25)	3.968
(30)	$\bar{1}$.999	(29)	0.992	(28)	1.985	(27)	2.986	(26)	3.975
	1.994½		0.987		1.984		2.982		3.971

SECOND SERIES.

GLASS SCALE.

	mm.		mm.		mm.		mm.		mm.
	0.5		0.4		0.3		0.2		0.1
	r.		r.		r.		r.		r.
(1)	0.045	(2)	1.024	(3)	2.030	(4)	3.037	(5)	4.023
(10)	0.061	(9)	1.042	(8)	2.039	(7)	3.030	(6)	4.024
(31)	0.011	(32)	1.019	(33)	2.003	(34)	3.010	(35)	4.001
(40)	0.041	(39)	1.020	(38)	2.011	(37)	3.009	(36)	4.000
	0.039½		1.026		2.021		3.021½		4.012

METAL SCALE.

	m.		m.		m.		m.		m.
	1.0002		1.0001		1.0000		0.9999		0.9998
	r.		r.		r.		r.		r.
(11)	$\bar{1}$.969	(12)	0.973	(13)	1.970	(14)	2.972	(15)	3.962
(20)	1.989	(19)	0.990	(15)	1.974	(17)	2.967	(16)	3.054
(21)	1.987	(22)	0.986	(23)	1.980	(24)	2.976	(25)	3.969
(30)	$\bar{1}$.980	(29)	0.980	(28)	1.969	(27)	2.974	(26)	3.065
	1.981		0.982		1.973		2.972		3.962½

February 5.

THIRD SERIES.

GLASS SCALE.

	mm.		mm.		mm.		mm.		mm.
	0.5		0.4		0.3		0.2		0.1
	r.		r.		r.		r.		r.
(1)	0.005	(2)	0.991	(3)	1.979	(4)	2.990	(5)	3.994
(10)	$\bar{1}$.995	(9)	0.995	(8)	1.993	(7)	2.990	(6)	3.971
(31)	1.981	(32)	0.980	(33)	1.969	(34)	2.965	(35)	3.978
(40)	1.989	(39)	0.986	(38)	1 974	(37)	2.971	(36)	3.972
	$\bar{1}$.992½		0.988		1.979		2.979		3.979

METAL SCALE.

	m.		m.		m.		m.		m.
	1.0002		1.0001		1.0000		0.9999		0.9998
	r.		r.		r.		r.		r.
(11)	1.982	(12)	0.992	(13)	1.978	(14)	2.980	(15)	3.974
(20)	0.001	(19)	1.000	(18)	1.990	(17)	2.990	(16)	3.972
(21)	0.001	(22)	1.006	(23)	1.992	(24)	2.988	(25)	3.973
(30)	0.004	(29)	0.997	(28)	1.991	(27)	2.986	(26)	3.977
	$\bar{1}$.997		0.999		1.988		2.986		3.974

FOURTH SERIES.

GLASS SCALE.

	mm.		mm.		mm.		mm.		mm.
	0.5		0.4		0.3		0.2		0.1
	r.		r.		r.		r.		r.
(1)	0.036	(2)	1.049	(3)	2.020	(4)	3.011	(5)	4.019
(10)	0.037	(9)	1.028	(8)	2.012	(7)	3.016	(6)	4.024
(31)	0.021	(32)	1.017	(33)	2.000	(34)	3.000	(35)	4.008
(40)	0.037	(39)	1.023	(38)	2.000	(37)	2.999	(36)	3.996
	0.033		1.029		2.008		3.006½		4.012

METAL SCALE.

	m.		m.		m.		m.		m.
	1.0002		1.0001		1.0000		0.9999		0.9998
	r.		r.		r.		r.		r.
(11)	$\bar{1}$.992	(12)	0.990	(13)	1.992	(14)	2.982	(15)	3.978
(20)	$\bar{1}$.994	(19)	0.996	(18)	1.986	(17)	2.982	(16)	3.973
(21)	$\bar{1}$.999	(22)	0.995	(23)	1.985	(24)	2.980	(25)	3.974
(30)	$\bar{1}$.999	(29)	1.000	(28)	1.993	(27)	2.985	(26)	3.974
	$\bar{1}$.996		0.995		1.989		2.982		3.975

February 6.

FIFTH SERIES.

GLASS SCALE.

	mm.		mm.		mm.		mm.		mm.
	0.5		0.4		0.3		0.2		0.1
	r.		r.		r.		r.		r.
(1)	$\bar{1}$.990	(2)	0.983	(3)	1.981	(4)	2.990	(5)	3.987
(10)	$\bar{1}$.989	(9)	0.986	(8)	1.980	(7)	2.990	(6)	3.980
(31)	$\bar{1}$.953	(32)	0.969	(33)	1.968	(34)	2.977	(35)	3.969
(40)	$\bar{1}$.970	(39)	0.970	(38)	1.951	(37)	2.962	(36)	3.973
	$\bar{1}$.975½		0.977		1.970		2.980		3.977

METAL SCALE.

	m.		m.		m.		m.		m.
	1.0002		1.0001		1.0000		0.9999		0.9998
	r.		r.		r.		r.		r.
(11)	$\bar{1}$.982	(12)	0.985	(13)	1.984	(14)	2.978	(15)	3.972
(20)	$\bar{1}$.994	(19)	0.990	(18)	1.982	(17)	2.980	(16)	3.970
(21)	$\bar{1}$.992	(22)	0.990	(23)	1.985	(24)	2.981	(25)	3.972
(30)	$\bar{1}$.996	(29)	0.994	(28)	1.989	(27)	2.981	(26)	3.972
	$\bar{1}$.991		0.990		1.985		2.980		3.971½

SIXTH SERIES.

GLASS SCALE.

	mm.		mm.		mm.		mm.		mm.
	0.5		0.4		0.3		0.2		0.1
	r.		r.		r.		r.		r.
(1)	0.020	(2)	1.007	(3)	1.999	(4)	2.990	(5)	3.986
(10)	0.024	(9)	1.010	(8)	1.998	(7)	2.991	(6)	4.000
(31)	$\bar{1}$.985	(32)	0.979	(33)	1.976	(34)	2.973	(35)	3.970
(40)	0.002	(39)	0.990	(38)	1.968	(37)	2.982	(36)	3.980
	0.008		0.996½		1.985		2.984		3.984

SIXTH SERIES—Continued.

METAL SCALE.

	m.		m.		m.		m.		m.
	1.0001		1.0000		0.9999		0.9998		0.9997
	r.		r.		r.		r.		r.
(11)	0.001	(12)	0.993	(13)	1.996	(14)	2.990	(15)	4.010
(20)	0.012	(19)	1.001	(18)	1.996	(17)	2.990	(16)	4.019
(21)	0.009	(22)	1.000	(23)	1.995	(24)	2.984	(25)	4.023
(30)	0.008	(29)	0.997	(28)	1.997	(27)	2.984	(26)	4.019
	0.007½		0.998		1.996		2.987		4.018

February 7.

SEVENTH SERIES.

GLASS SCALE.

	mm.		mm.		mm.		mm.		mm.
	0.5		0.4		0.3		0.2		0.1
	r.		r.		r.		r.		r.
(1)	0.026	(2)	1.022	(3)	2.016	(4)	3.005	(5)	4.013
(10)	0.032	(9)	1.020	(8)	2.004	(7)	3.023	(6)	4.010
(31)	$\bar{1}$.982	(32)	0.972	(33)	1.962	(34)	2.962	(35)	3.960
(40)	$\bar{1}$.990	(39)	0.981	(38)	1.965	(37)	2.969	(36)	3.980
	0.007½		1.019		1.987		2.990		3.991

METAL SCALE.

	m.		m.		m.		m.		m.
	1.0001		1.0000		0.9999		0.9998		0.9997
	r.		r.		r.		r.		r.
(11)	0.018	(12)	1.021	(13)	2.018	(14)	3.008	(15)	4.036
(20)	0.023	(19)	1.030	(18)	2.020	(17)	3.007	(16)	4.035
(21)	0.021	(22)	1.023	(23)	2.015	(24)	3.012	(25)	4.039
(30)	0.019	(29)	1.025	(28)	2.011	(27)	3.003	(26)	4.031
	0.020		1.025		2.016		3.007½		4.035

EIGHTH SERIES.

GLASS SCALE.

	mm.		mm.		mm.		mm.		mm.
	0.5		0.4		0.3		0.2		0.1
	r.		r.		r.		r.		r.
(1)	0.020	(2)	1.014	(3)	1.990	(4)	2.995	(5)	3.997
(10)	0.011	(9)	1.004	(8)	1.994	(7)	2.996	(6)	3.995
(31)	$\bar{1}$.983	(32)	0.980	(33)	1.977	(34)	2.976	(35)	3.976
(40)	0.003	(39)	1.000	(38)	1.980	(37)	2.978	(36)	3.976
	0.004		0.999½		1.985		2.986		3.986

METAL SCALE.

	m.		m.		m.		m.		m.
	1.0001		1.0000		0.9999		0.9998		0.9997
	r.		r.		r.		r.		r.
(11)	0.005	(12)	1.013	(13)	2.000	(14)	2.995	(15)	4.019
(20)	0.011	(19)	1.016	(18)	2.010	(17)	2.995	(16)	4.019
(21)	0.010	(22)	1.013	(23)	2.004	(24)	2.997	(25)	4.019
(30)	0.013	(29)	1.007	(28)	2.007	(27)	3.003	(26)	4.021
	0.010		1.012		2.005		2.997½		4.019½

February 8.

NINTH SERIES.

GLASS SCALE.

	mm. 0.5		mm. 0.4		mm. 0.3		mm. 0.2		mm. 0.1
	r.		r.		r.		r.		r.
(1)	0.034	(2)	1.034	(3)	2.033	(4)	3.025	(5)	4.011
(10)	0.038	(9)	1.022	(8)	2.021	(7)	3.028	(6)	4.016
(31)	0.006	(32)	1.003	(33)	1.990	(34)	2.983	(35)	3.993
(40)	0.009	(39)	1.000	(38)	1.995	(37)	2.990	(36)	3.993
	0.022		1.015		2.010		3.006½		4.003

METAL SCALE.

	m. 1.0001		m. 1.0000		m. 0.9999		m. 0.9998		m. 0.9997
	r.		r.		r.		r.		r.
(11)	0.020	(12)	1.020	(13)	2.014	(14)	3.011	(15)	4.036
(20)	0.029	(19)	1.023	(18)	2.019	(17)	3.012	(16)	4.036
(21)	0.030	(22)	1.024	(23)	2.016	(24)	3.010	(25)	4.031
(30)	0.018	(29)	1.024	(28)	2.010	(27)	3.011	(26)	4.031
	0.024		1.023		2.015		3.011		4.033½

February 10.

TENTH SERIES.

GLASS SCALE.

	mm. 0.5		mm. 0.4		mm. 0.3		mm. 0.2		mm. 0.1
	r.		r.		r.		r.		r.
(1)	0.006	(2)	1.001	(3)	1.990	(4)	2.989	(5)	4.007
(10)	0.029	(9)	1.010	(8)	2.009	(7)	2.993	(6)	4.012
(31)	0.000	(32)	1.010	(33)	2.003	(34)	3.000	(35)	4.013
(40)	0.026	(39)	1.018	(38)	2.009	(37)	3.004	(36)	4.018
	0.015		1.010		2.003		2.996½		4.012½

METAL SCALE.

	m. 1.0001		m. 1.0000		m. 0.9999		m. 0.9998		m. 0.9997
	r.		r.		r.		r.		r.
(11)	0.046	(12)	1.041	(13)	2.042	(14)	3.023	(15)	4.054
(20)	0.050	(19)	1.041	(18)	2.041	(17)	3.023	(16)	4.055
(21)	0.044	(22)	1.043	(23)	2.040	(24)	3.032	(25)	4.052
(30)	0.043	(29)	1.049	(28)	2.036	(27)	3.026	(26)	4.059
	0.046		1.043½		2.040		3.026		4.055

February 11.

ELEVENTH SERIES.

GLASS SCALE.

	mm. 0.5		mm. 0.4		mm. 0.3		mm. 0.2		mm. 0.1
	r.		r.		r.		r.		r.
(1)	0.034	(2)	1.024	(3)	2.003	(4)	3.010	(5)	4.022
(10)	0.024	(9)	1.018	(8)	2.006	(7)	3.010	(6)	4.014
(31)	$\bar{1}$.969	(32)	0.974	(33)	1.964	(34)	2.964	(35)	3.976
(40)	$\bar{1}$.985	(39)	0.972	(38)	1.964	(37)	2.974	(36)	3.980
	0.003		0.997		1.984		2.989½		3.998

ELEVENTH SERIES—Continued.

METAL SCALE.

	m.		m.		m.		m.		m.
	1.0000		0.9999		0.9998		0.9997		0.9996
	r.		r.		r.		r.		r.
(11)	0.021	(12)	1.025	(13)	2.011	(14)	3.041	(15)	4.028
(20)	0.034	(19)	1.019	(18)	2.019	(17)	3.041	(16)	4.016
(21)	0.034	(22)	1.025	(23)	2.015	(24)	3.037	(25)	4.015
(30)	0.032	(29)	1.019	(28)	2.014	(27)	3.030	(26)	4.020
	0.030		1.022		2.015		3.037		4.020

TWELFTH SERIES.

GLASS SCALE.

	mm.		mm.		mm.		mm.		mm.
	0.5		0.4		0.3		0.2		0.1
	r.		r.		r.		r.		r.
(1)	0.010	(2)	1.001	(3)	1.985	(4)	2.977	(5)	3.975
(10)	0.028	(9)	1.020	(8)	1.992	(7)	2.987	(6)	3.992
(31)	0.000	(32)	0.980	(33)	1.964	(34)	2.960	(35)	3.970
(40)	0.000	(39)	0.993	(38)	1.970	(37)	2.952	(36)	3.970
	0.009½		0.998½		1.978		2.969		3.977

METAL SCALE.

	m.		m.		m.		m.		m.
	1.0000		0.9999		0.9998		0.9997		0.9996
	r.		r.		r.		r.		r.
(11)	$\bar{1}$.979	(12)	0.979	(13)	1.965	(14)	2.995	(15)	3.960
(20)	$\bar{1}$.996	(19)	0.991	(18)	1.974	(17)	2.995	(16)	3.970
(21)	$\bar{1}$.993	(22)	0.985	(23)	1.976	(24)	2.991	(25)	3.965
(30)	$\bar{1}$.990	(29)	0.983	(28)	1.964	(27)	2.991	(26)	3.974
	$\bar{1}$.989½		0.984½		1.970		2.993		3.967

THIRTEENTH SERIES.

GLASS SCALE.

	mm.		mm.		mm.		mm.		mm.
	0.5		0.4		0.3		0.2		0.1
	r.		r.		r.		r.		r.
(1)	$\bar{1}$.993	(2)	0.982	(3)	1.964	(4)	2.967	(5)	3.961
(10)	0.010	(9)	0.984	(8)	1.970	(7)	2.970	(6)	3.975
(31)	$\bar{1}$.970	(32)	0.974	(33)	1.951	(34)	2.953	(35)	3.966
(40)	1.993	(39)	0.982	(38)	1.968	(37)	2.960	(36)	3.967
	$\bar{1}$.991½		0.980½		1.963		2.962½		3.967

METAL SCALE.

	m.		m.		m.		m.		m.
	1.0000		0.9999		0.9998		0.9997		0.9996
	r.		r.		r.		r.		r.
(11)	0.041	(12)	1.030	(13)	2.012	(14)	3.037	(15)	4.010
(20)	0.043	(19)	1.030	(18)	2.020	(17)	3.040	(16)	4.010
(21)	0.039	(22)	1.028	(23)	2.013	(24)	3.029	(25)	4.010
(30)	0.039	(29)	1.030	(28)	2.008	(27)	3.030	(26)	4.017
	0.040½		1.029½		2.013		3.034		4.012

February 12.

FOURTEENTH SERIES.

GLASS SCALE.

	mm. 0.5		mm. 0.4		mm. 0.3		mm. 0.2		mm. 0.1
	r.		r.		r.		r.		r.
(1)	0.060	(2)	1.040	(3)	2.026	(4)	3.040	(5)	4.054
(10)	0.063	(9)	1.060	(8)	2.037	(7)	3.039	(6)	4.051
(31)	0.020	(32)	1.014	(33)	2.007	(34)	3.010	(35)	4.014
(40)	0.033	(39)	1.028	(38)	2.008	(37)	3.011	(36)	4.025
	0.044		1.035½		2.019½		3.025		4.036

METAL SCALE.

	m. 1.0000		m. 0.9999		m. 0.9998		m. 0.9997		m. 0.9996
	r.		r.		r.		r.		r.
(11)	0.021	(12)	1.016	(13)	2.000	(14)	3.028	(15)	4.006
(20)	0.019	(19)	1.029	(18)	2.010	(17)	3.030	(16)	3.996
(21)	0.036	(22)	1.022	(23)	2.013	(24)	3.036	(25)	4.003
(30)	0.031	(29)	1.019	(28)	1.996	(27)	3.020	(26)	4.006
	0.027		1.021½		2.005		3.028½		4.003

FIFTEENTH SERIES.

GLASS SCALE.

	mm. 0.5		mm. 0.4		mm. 0.3		mm. 0.2		mm. 0.1
	r.		r.		r.		r.		r.
(1)	0.020	(2)	1.002	(3)	2.003	(4)	3.008	(5)	3.997
(10)	0.018	(9)	1.019	(8)	2.001	(7)	3.004	(6)	3.992
(31)	1.989	(32)	0.980	(33)	1.984	(34)	2.982	(35)	3.976
(40)	0.012	(39)	0.999	(38)	1.974	(37)	2.980	(36)	3.979
	0.010		1.000		1.990½		2.993½		3.986

METAL SCALE.

	m. 1.0000		m. 0.9999		m. 0.9998		m. 0.9997		m. 0.9996
	r.		r.		r.		r.		r.
(11)	0.019	(12)	1.016	(13)	1.994	(14)	3.025	(15)	4.004
(20)	0.028	(19)	1.027	(18)	2.006	(17)	3.035	(16)	4.005
(21)	0.030	(22)	1.022	(23)	2.013	(24)	3.027	(25)	4.004
(30)	0.026	(29)	1.024	(28)	2.010	(27)	3.024	(26)	4.006
	0.026		1.022		2.006		3.028		4.005

The following tables exhibit the results of all these measures:

GLASS SCALE.

	mm. mm. 0.5 to 0.4	mm. mm. 0.4 to 0.3	mm. mm. 0.3 to 0.2	mm. mm. 0.2 to 0.1
	r.	r.	r.	r.
First series	0.989	0.981½	0.997	0.996½
Second series	0.987	0.994½	1.001	0.990½
Third series.................. .	0.985½	0.991	1.000	1.000
Fourth series	0.986½	0.979	0.998½	1.005
Fifth series	1.001½	0.993	1.010	1.000
Mean..................	0.994	0.988	1.001	0.998

GLASS SCALE—Continued.

	mm. mm. 0.5 to 0.4	mm. mm. 0.4 to 0.3	mm. mm. 0.3 to 0.2	mm. mm. 0.2 to 0.1
	r.	r.	r.	r.
Sixth series	0.989	0.989	0.999	1.000
Seventh series	0.986	0.988	1.003	1.001
Eighth series	0.995	0.986	1.001	1.000
Ninth series	0.993½	0.995	0.997	0.997
Tenth series	0.994½	0.993	0.994	1.016
Mean	0.992	0.990	0.999	1.003
	r.	r.	r.	r.
Eleventh series	0.994	0.987	1.005	1.008½
Twelfth series	0.989	0.979	0.991	1.008
Thirteenth series	0.989	0.982½	0.999	1.005
Fourteenth series	0.991½	0.984	1.005½	1.006
Fifteenth series	0.990	0.990½	1.003	0.992½
Mean	0.991	0.985	1.001	1.004
Mean of 15	0.992	0.988	1.000	1.002

Probable error of a mean of 15 = ± 0r.001.

METAL SCALE.

	m. 1.0002 to 1.0001	m. 1.0001 to 1.0000	m. 1.0000 to 0.9999	m. 0.9999 to 0.9998
	r.	r.	r.	r.
First series	0.989	0.997	0.998	0.990
Second series	1.001	0.991	0.999	0.990
Third series	1.002	0.989	0.998	0.988
Fourth series	0.999	0.994	0.993	0.992½
Fifth series	0.999	0.995	0.995	0.991½
Mean	0.998	0.993	0.997	0.990

	m. 1.0001 to 1.0000	m. 1.0000 to 0.9999	m. 0.9999 to 0.9998	m. 0.9998 to 0.9997
	r.	r.	r.	r.
Sixth series	0.990	0.998	0.991	1.031
Seventh series	1.004½	0.991	0.991½	1.027½
Eighth series	1.002½	0.993	0.992	1.022
Ninth series	1.001½	0.992	0.996	1.022½
Tenth series	0.998	0.996	0.986	1.029
Mean	0.999	0.994	0.991	1.026

METAL SCALE—Continued.

	m. 1.0000 to 0.9999	m. 0.9999 to 0.9998	m. 0.9998 to 0.9997	m. 0.9997 to 0.9996
	r.	r.	r.	r.
Eleventh series	0.992	0.993	1.022½	0.982½
Twelfth series	0.995	0.985	1.023	0.978
Thirteenth series	0.989	0.984	1.021	0.978
Fourteenth series	0.992	0.986	1.024	0.974
Fifteenth series	0.996½	0.983	1.022	0.977
Mean	0.993	0.986	1.022½	0.978

Probable error of a mean of 15 = $0^r.0006$.

The following table shows the apparent inequalities of different revolutions of the screws:

	Excess of measure on 1^r to 2^r / Over measure on 0^r to 1^r	Excess of measure on 2^r to 3^r / Over measure on 1^r to 2^r	Excess of measure on 3^r to 4^r / Over measure on 2^r to 3^r
m. m.	r.		
1.0001 to 1.0000	− 0.006	r.	
1.0000 to 0.9999	+ 0.001	+ 0.003	r.
0.9999 to 0.9998		+ 0.005	− 0.001
0.9999 to 0.9997			+ 0.003½
Mean	− 0.002½	+ 0.004	+ 0.001
By glass scale	− 0.004	+ 0.012	+ 0.002

These results accord in showing certain inequalities in different parts of the screw; but I shall neglect these as being of no importance for the measures of the pendulum. There would seem, from these measures, to be an inequality in the spaces on the glass scale; but measures made with a higher power have proved that these are simply due to constant errors of judgment in bisecting the lines on glass.

The mean value of the divisions of the glass scale (giving the middle two double weight, according to the requirement of the theory of least squares) is $0^r.995$, whence we may assume

$$\tfrac{1}{10} \text{ millimeter} = 0^r.996.$$

This gives us for the spaces on the metallic scale

m. 1.0002 to 1.0001	m. 1.0001 to 1.0000	m. 1.0000 to 0.9999	m. 0.9999 to 0.9998	m. 0.9998 to 0.9997	m. 0.9997 to 0.9996
mm.	mm.	mm.	mm.		
0.1002	0.0997	0.1001	0.0994	mm.	
	0.1003	0.0998	0.0995	0.1030	mm.
		0.0997	0.0990	0.1026	0.0982
0.1002	0.1000	0.0999	0.0993	0.1028	0.0982

The following are comparisons of the spaces between the three lines at the beginning of the meter with those between the lines $0^{mm}.1$, $0^{mm}.2$, $0^{mm}.3$ of the same glass scale:

First comparison.

	0.3	0.2	0.1
GLASS SCALE.	*r.*	*r.*	*r.*
	0.942	1.932	2.921
	0.944	1.940	2.922
Mean....	0.943	1.936	2.921
METAL SCALE.	−0.0	0.0	+0.1
	0.978	1.970	2.967
	1.002	1.992	2.970
Mean....	0.990	1.981	2.969
	0.992	1.997	2.980
	1.005	1.990	2.970
Mean....	0.998	1.993	2.975
GLASS SCALE.			
	0.911	1.888	2.907
	0.907	1.910	2.891
Mean....	0.909	1.899	2.899

Second comparison. Temp., 13°.5 C.

	0.3	0.2	0.1
GLASS SCALE.	*r.*	*r.*	*r.*
	1.021	2.019	3.016
	1.005	2.005	3.016
Mean....	1.013	2.012	3.016
METAL SCALE.	−0.0	0.0	+0.1
	0.990	2.022	3.019
	1.020	2.016	3.026
Mean....	1.005	2.019	3.022
	1.013	2.016	3.015
	1.019	2.009	3.005
Mean....	1.016	2.013	3.010
GLASS SCALE.			
	0.994	2.000	3.009
	0.980	1.995	3.004
Mean....	0.987	1.998	3.006

The above measures were made on the part of the metallic lines usually used. The following were taken somewhat nearer the line separating the meter-scale from that of the metallic thermometer:

Third comparison. 13° C.

	0.3	0.2	0.1
GLASS SCALE.	*r.*	*r.*	*r.*
	1.032	2.050	3.017
	1.040	2.052	3.028
Mean..	1.036	2.051	3.023
METAL SCALE.	−0.1	0.0	+0.1
	1.060	2.051	3.053
	1.066	2.050	3.072
Mean..	1.063	2.051	3.063
	1.079	2.048	3.036
	1.052	2.050	3.042
Mean..	1.065	2.049	3.039
GLASS SCALE.			
	1.010	2.026	3.014
	1.038	2.013	3.024
Mean..	1.024	2.019	3.019

Fourth comparison.

	0.3	0.2	0.1
GLASS SCALE.	*r.*	*r.*	*r.*
	1.012	2.018	3.003
	1.020	2.001	3.006
Mean..	1.016	2.010	3.005
METAL SCALE.	−0.1	0.0	+0.1
	1.010	1.989	3.014
	1.005	1.990	3.019
Mean..	1.008	1.989	3.016
	1.011	1.990	3.002
	1.009	1.981	3.006
Mean..	1.010	1.985	3.004
GLASS SCALE.			
	0.990	1.990	2.995
	1.013	2.010	3.016
Mean..	1.002	2.000	3.005

Fifth comparison.

	0.3	0.2	0.1
GLASS SCALE.	*r.*	*r.*	*r.*
	1.018	2.019	3.012
	1.031	2.025	3.002
Mean..	1.024	2.022	3.007
METAL SCALE.	−0.1	0.0	+0.1
	1.008	1.992	2.988
	1.008	1.997	3.008
Mean..	1.008	1.995	2.998
	1.010	1.988	2.999
	1.007	1.987	3.008
Mean..	1.008	1.987	3.004
GLASS SCALE.			
	0.974	1.990	2.986
	0.970	1.979	2.965
Mean..	0.972	1.984	2.975

The following are the results of these comparisons:

GLASS SCALE.

	0.3 to 0.2	0.2 to 0.1
	r.	*r.*
First comparison	0.991	0.993
Second comparison	1.005	1.007
Third comparison	1.005	0.985
Fourth comparison	0.996	1.000
Fifth comparison	1.000	0.988
	0.999	0.995

METAL SCALE.

	−0.1 to 0.0	0.0 to +0.1
First comparison	0.993	0.984
Second comparison	1.005	1.001
Third comparison	0.985	1.001
Fourth comparison	0.979	1.023
Fifth comparison	0.983	1.010
	0.989	1.004

From this it appears that the values of the spaces on the metallic scale are

−0.1 to 0.0	0.0 to +0.1
$98^{\mu}.9$	$100^{\mu}.8$

ON THE VALUE OF THE SCREW-REVOLUTIONS OF THE UPPER MICROSCOPE OF THE REPSOLD VERTICAL COMPARATOR.

On 1878, January 21, a glass scale of 68 teeth of Rutherfurd's ruling-machine per division was measured by this micrometer. The following are the results:

	Line 1 to line 2. (0^r to 1^r)	Line 2 to line 3. (1^r to 2^r)	Line 3 to line 4. (2^r to 3^r)	Line 4 to line 5. (3^r to 4^r)
	r.	*r.*	*r.*	*r.*
	1.000	0.994	0.999	0.997
	1.000	0.992	0.999	0.993
	1.005	1.000	0.996	0.993
	1.008	0.994	1.003	0.993
Means....	1.003	0.995	0.999	0.994

The probable error of each mean is $\pm 0^r.001$. We, therefore, have for the corrections of tenths of millimeters measured on these parts of the screw in order to bring them to the mean value between 1^r and 2^r

r. *r.*	*r.*
0 to 1	−0.006
1 to 2	+0.002
2 to 3	−0.002
3 to 4	+0.003

The corrections to bring the means of three lines measured on three parts of the screw to the middle are:

Correction to mean of 0^r, 1^r, and 2^r, to bring to 2^r $= + 1^r.002$
Correction to mean of 2^r, 3^r, and 4^r, $= - 0^r.999$
Correction to mean of 1^r, 2^r, and 3^r, $= + 0^r.0013$

The values of the two revolutions from 1^r to 3^r are best obtained from the observations made in comparing the pendulum with the standard at different stations.

	m.		m.		r.	r.
At Geneva,	0.9999	to	1.0001	on pendulum-meter measured	1.994	± 0.001
At Paris,	− 0.0001	to	+ 0.0001	on same meter measured	1.991	± 0.001
At Berlin,	− 0.0001	to	+ 0.0001	on same meter measured	1.996	± 0.001
At Kew,	− 0.0001	to	+ 0.0001	on same meter measured	2.001	± 0.001
At Hoboken,	0.9997	to	0.9999	on same meter measured	2.022	

The known values of these intervals give for the measure of $\frac{2}{10}$ of a millimeter

	r.
From Geneva observations	1.995
From Paris observations	1.994
From Berlin observations	1.999
From Kew observations	2.004
From Hoboken observations	2.001

As the focalization of this microscope is made with difficulty, it is not surprising that its magnifying power should differ by some thousandths of itself. The focalization at Berlin was particularly good, and $1^r.999$ may be taken as the true value, giving for the value of one revolution between 1^r and 3^r

$$0^{mm}.10005$$

VALUE OF SCREW REVOLUTIONS OF THE LOWER MICROSCOPE.

Corresponding distances measured with the lower microscope, between marks on the pendulum-meter, were obtained from the observations at the different stations, as follows:

	m.		m.		r.
At Geneva,	− 0.0001	to	+ 0.0001	measured	1.987
At Paris,	0.9999	to	1.0001	measured	1.991
At Berlin,	0.9999	to	1.0001	measured	1.991
At Kew,	0.9997	to	0.9999	measured	2.014
At Hoboken	− 0.0001	to	+ 0.0001	measured	2.002

Hence, by substituting the values of the intervals, we obtain as the value of $\frac{2}{10}$mm. in revolutions of the microscope screw:

	r.
Geneva observations	1.990
Paris observations	1.992
Berlin observations	1.992
Kew observations	1.993
Hoboken observations	2.005

Adopting, as before, the Berlin value, we obtain as the value of one revolution,

$$0^{mm}.1004$$

RESULTS OF OBSERVATIONS OF LENGTH.

Professor Förster gives as the length of the German pendulum-meter, compared with No. 1605, in a letter dated June 24, 1878:

$$\text{B. P.} - 1605 = -103^{\mu}.5 - 0^{\mu}.2\,(\tau' - 17^{\circ}.0).$$

The following is the translation of a communication from Professor Förster, giving the length and distance between the lines at the end of meter No. 49:

BERLIN, *March* 29, 1878.

Summary of the results of comparisons of lengths between the standard meter No. 49 *and others.*

No. 49 is a brass bar with a shoulder at each end. The surfaces of these shoulders are in a horizontal plane passing through the axis of the bar. Let into surface of each shoulder is a silver plate having three lines ruled on it. The contact-cylinders used for comparisons between this bar (which is a line measure) and end measures may be considered a part of No. 49.

Standard No. 49, described above, was carefully compared at different temperatures with standard meter No. 1605, belonging to the "Normal Standards Commission." No. 1605 is a line measure of brass, entirely prismatic in form. The defining lines are ruled on silver plates let into the surface of the bar. In these comparisons, both bars were supported on a plane surface of brass. No 1605 had repeatedly been compared with the platinum meter belonging to the commission. The length of the platinum meter was derived from comparison made in 1860 between it and the mètre du Conservatoire and the mètre des Archives. But the direct comparisons between No. 1605 and the platinum meter were not as accurate as the direct comparisons between the platinum meter and No. 49, the results of which will be given farther on.

The absolute length of our platinum meter is not as yet known with sufficient accuracy, because the comparison between it and the mètre des Archives gave a result differing nearly 0.02^{mm} from the result of comparisons between it and the mètre du Conservatoire, while the actual difference between these Paris meters is said not to exceed 0.003^{mm}.

At the same time, neither the direct nor the indirect comparisons between No. 49 and the platinum meter have as much value as the more accurate comparisons between No. 49 with No. 1605, because in these last comparisons the errors due to our former defective arrangements for securing uniformity of temperatures are less sensible on account of the similarity of the material of which both bars are composed, than in comparisons between brass and platinum, and also because it will soon be possible to compare, by the aid of the most refined means, No. 1605 with the new prototype.

The results of all comparisons referring to No. 49 will be given in the following pages, and will serve as data for a final reduction at some future time. We begin with the most important, namely, the comparisons between No. 49 and No. 1605.

The lines defining the length of No. 49 are each midway between two other lines distant from them about 7^{mm}. The latter are used in connection with the contact-cylinder in comparisons between No. 49 and end measures. Therefore, No. 1605 could be compared with three sets of meter-defining lines on No. 49, to wit:

With the meter defined by the central lines of each group of 3 near the ends of the bar.
With the meter defined by the outside line on the left hand and the inside line on the right.
With the meter defined by the inside line on the left and the inside line on the right.

Of course, all these measurements refer to that part of the transverse lines lying midway between the two longitudinal ones.

Very accurate micrometric measurements give the following values for the four spaces between the transverse lines of No. 49, at a temperature of 0° C. Beginning on the outside of one end of the bar the several lines are numbered consecutively, 1, 2, 3, and beginning on the inside of the other end, 4, 5, 6:

		mm.		*mm.*
Space 1–2	=	7.3796	±	0.00016
Space 2–3	=	7.3761	±	0.00022
Space 4–5	=	7.3782	±	0.00023
Space 5–6	=	7.3774	±	0.00018

Putting .001 millimeter = μ, we find from the foregoing measurements that the meter defined by the lines 1–4 is longer than that defined by the middle lines 2–5, by $1^{\mu}.4$, and also that the meter between the lines 3–6 is longer than the meter between the lines 2–5, by $1^{\mu}.3$.

By making use of the values thus found and reducing all comparisons between No. 1605 and No. 49 to the meter defined on the latter by the middle or principal lines 2–5, we get:

Temperature (C.)	No. 1605 — No. 49
°	μ
4.07	— 39.5
21.53	— 42.0
21.61	— 42.1
23.42	— 41.4
23.44	— 41.55
23.47	— 40.65
23.49	— 41.45
23.63	— 41.60
23.80	— 42.45
25.37	— 42.45
25.48	— 41.65
25.59	— 41.95

Reducing these results by least squares we deduce the following formula for the difference of length 1605 — 49:

$$1605 - 49 = \left\{ \begin{array}{rcr} \overset{\mu}{-\ 39.08} & - & 0.110\,t \\ \pm\ \ 0.42 & \pm & .019\,t \end{array} \right.$$

where t stands for temperature in terms of the Centigrade scale. The probable errors of the numerical quantities are denoted by the figures having the signs $\pm$ prefixed, and these will throughout this paper be written below or next to the quantities to which they refer. The following table, calculated by the above formula, gives the differences in length (1605 — 49) and their probable errors at the given temperatures:

Temperature.	1605 — 49	
°	μ	μ
0	— 39.1	$\pm$ 0.4
+ 5	39.6	0.3
+ 10	40.2	0.2
+ 15	40.7	0.1
+ 20	41.3	0.1
+ 25	41.8	0.1

In regard to the comparisons between No. 49 and the platinum meter (end measure), it is necessary to explain the manner in which the contact-cylinders were used. The contact ends of the two cylinders I and II are spherical surfaces. A glass scale, which can be distinctly seen by microscopes supplied with the necessary reflecting apparatus, with transverse and two longitudinal lines, is let into the axis of each cylinder in such a manner that the point on the sixth transverse line midway between the two longitudinal lines is in the center of the sphere of which the spherical contact surface is a part. The transverse lines are reckoned from the contact surface along the axis of the cylinder. When the two cylinders are in contact the relation between the sum of the radii of the two spherical abutting surfaces and the distance between the transverse lines before mentioned is independent of small variations in the inclination of the axes of the cylinders to each other. We can therefore deduce with perfect accuracy the linear value of the sum of the two radii by measuring the distance between the specified transverse lines when the cylinders are in contact, and can thus reduce the pointings on the centers of the spherical surfaces to their point of contact; a reduction which is necessary in the comparison of the end measure with the line measure. Because the reference-points of the scales are in the centers of the spheres of which the abutting surfaces are part, no sensible error need be apprehended from changes in the relative position of the axes of the cylinders when they are in contact with the abutting surfaces of the end measure. The length of the sum of the two radii of the two cylinders in contact, that is, the distance between the specified transverse lines, was measured on a good transverse comparator, and was

referred to the same standard scale used in measuring the auxiliary spaces on standard No. 49. Thus the reduction of the distance between the defining lines of the cylinders when in contact with the platinum meter to the length of the platinum meter itself, can be referred to the same standard scale, and will be liable to the same errors as the reduction of the extreme lines on No. 49 to the middle or standard lines. As far as the use of the auxiliary distances measured on the transverse comparator are concerned the effect of errors of graduation of the standard scale to which they are referred might have been eliminated from the comparison between the line and end measure. Full attention was not paid to this consideration in these comparisons. However, only the differences of the errors of graduation of adjacent lines of the standard scale came into account, and these were determined with extraordinary precision, and were carefully taken into account in the computations.

The distance between the defining lines of the glass scales in the axes of the cylinders when the latter were in carefully adjusted contact is given by the following expression:

$$C = \begin{cases} \overset{mm.}{14.7432} + \overset{mm.}{0.000162}\ t. \\ \pm\ 0.00026 \end{cases}$$

For the sum of the auxiliary spaces 1–2 and 5–6 on No. 49, we get in conformity with the values previously given:

$$S = \begin{cases} \overset{mm.}{14.7570} + \overset{mm.}{0.000265} \times t. \\ \pm\ 0.00024 \end{cases}$$

At any temperature t°, the excess of the sum of the outside auxiliary spaces on No. 49, over the sum of the spaces between the point of contact of the cylinders and the defining lines of their scales, is therefore

$$S - C = \begin{cases} + \overset{\mu}{13.8} + \overset{\mu}{0.103}\ t. \\ \pm\ .35 \end{cases}$$

This value represents the correction which must be applied to the difference in length between the extreme lines on No. 49 and the distance between the defining lines in the cylinders when the latter are in contact with the abutting surfaces of the platinum meter.

Our comparisons give directly:

$$\lambda = (Pl + C) - (1605 + S),$$

and, therefore,

$$Pl - 1605 = \lambda + S - C,$$

and substituting the foregoing numerical values,

$$Pl - 1605 = \lambda + \overset{\mu}{13.8} + \overset{\mu}{0.103}\ t.$$

In this way were obtained the following differences of length between the platinum meter, defined by the distance between the middles of its end-surfaces, and standard No. 49, defined by the distance between the middle transverse line near each end, measured midway between the longitudinal lines:

Temperature.	Pl — 49	Calc. — Obs.
	μ	μ
+ 3.25	− 8.2	− 0.2
+ 6.28	− 39.2	+ 0.2
+ 23.55	− 213.1	− 0.1

From these values we deduce the following expression by the method of least squares:

$$Pl - 49 = \begin{cases} + \overset{\mu}{24.4} - \overset{\mu}{10.086}\ t \\ \pm\ 0.20 \pm\ 0.014\ t \end{cases}$$

by means of which the following tabulated values are computed:

Temperature.	Pl — 49	
°	μ	μ
0	+ 24.4	± 0.20
5	− 26.0	± 0.15
10	− 76.5	± 0.12
15	− 126.9	± 0.13
20	− 177.3	± 0.17
25	− 227.8	± 0.23

The uncertainty pertaining to these values may be much larger than the probable errors indicate because of the uncertainty of the relative expansion and of the imperfect methods of determining the temperatures, and because the observations are not sufficiently numerous.

If we take the result of the comparison made in Paris between our platinum meter and the mètre des Archives, namely: Mètre des A. — Pl = — $3^{\mu}.01$, we obtain the equation:

$$\text{M. d. A.} - \text{No. } 49 = \{ + 21^{\mu}.4 - 10^{\mu}.086\ t \}\cdot$$

This equation, however, is subject to doubt on account of the imperfection of the comparisons at Paris, previously mentioned, a doubt which can only be removed at some future time with the assistance of the more accurate equation established between 1605 and 49. The direct comparison between our platinum meter and the mètre des Archives (A) appears much less complete than the indirect comparison through the medium of the mètre du Conservatoire (C). On the assumption made at Paris that the coefficient of expansion of A, C, and Pl are nearly equal, the following results were obtained for the indirect comparisons. Direct observations between C and Pl gave:

$$\text{C} - \text{Pl} = - 16^{\mu}.2$$

But according to subsequent determinations (Procès-Verbaux de la Section Francaise, 1870), A — C = — $3^{\mu}.2$, it would follow that A — Pl = — $19^{\mu}.2$, and using this last equation, we get:

$$\text{A} - 49 = + 5^{\mu}.2 - 10.086\ t,$$

and if for 1° Centigrade we take the expansion = $8^{\mu}.60$, we obtain:

$$\text{No. } 49 = \overset{mm.}{999.9948} + \overset{mm.}{0.01869}\ t,$$

a value subject to a much greater uncertainty than is indicated by the probable errors given above on account of the imperfections of the Paris results.

The results of the scale values of the cylinders are given in conclusion (the lines designated by 1 are those nearest the contact ends):

Space.	Cylinder I.		Cylinder II.	
	μ		μ	
Line 1 to 2	54.2		49.4	
1 to 3	104.3	50.1	100.7	51.3
1 to 4	154.5	50.2	148.7	48.0
1 to 5	207.8	53.3	199.4	50.7
1 to 6	252.8	45.0	249.7	50.3
1 to 7	305.5	52.7	303.4	53.7
1 to 8	355.8	50.3	352.7	49.3
1 to 9	407.8	52.0	401.3	48.6
1 to 10	454.0	46.2	452.9	51.6
1 to 11	504.4	50.4	503.6	50.7

For the Imperial Commission on Weights and Measures.

[Signed] FOERSTER.

The comparisons made in 1875 between the U. S. and German pendulum-meters give:

$$\text{U. S. meter} - \text{German meter} = + 131^{\mu}.9,$$

and those made in 1877 give:

$$\text{U. S. meter} - \text{German meter} = + 131^{\mu}.3;$$

The mean of these values, or + $131^{\mu}.6$, is adopted. The comparisons in detail are given in the following tables. The unit is one-thousandth of the revolution of the micrometer-screws.

UNITED STATES COAST SURVEY.—COMPARISONS OF PRUSSIAN AND U. S. PENDULUM STANDARDS, 1875.

Date.	Time.	Which first.	Prussian.		U. S.		Prussian *minus* comparator.	U. S. *minus* comparator.	U. S. *minus* Prussian.	Mean mercurial ther.	Prussian met. ther.	U. S. met. ther.	U. S. – Pr. ther.	Select values for mean.
			Below.	Above.	Below.	Above.								
BOTH THERMOMETER SCALES DOWN.														
										°				
June 17	0.10 p. m.	Pr. ?	1362	1263	1125	1309	− 99	+184	+ 283	20. 1	2762	503	....	....
17	0.10 p. m.	U. S. ?	2041	1025	2058	2303	−1016	+245	+1261	19. 8	2900	556	....	....
17	6.24 p. m.	....	2041	1043	1037	2332	− 998	+295	+1293	19. 6	2932	629	....	....
18	10.20 a. m.	....	2119	894	2220	2250	−1225	+ 30	+1255	19. 7	2926	427	....	....
18	10.50 a. m.	....	2145	939	2195	2295	−1206	+100	+1306	19. 4	2906	427	....	....
18	4.15 p. m.	....	2124	941	2193	2268	−1183	+ 75	+1258	19. 4	2981	368	....	....
19	11.00 a. m.	....	2123	920	2212	2303	−1203	+ 91	+1294	19. 3	2973	358	....	....
19	1.30 p. m.	....	2556	1224	2408	2541	−1332	+133	+1465	....	2794	687	....	....
21	10.15 a. m.	U. S.	2552	1107	2457	2367	−1445	− 90	+1355	18. 8	+ 81	−287	−368	....
21	11.10 a. m.	Pr. ?	2545	1086	2454	2337	−1459	−117	+1342	19. 2	+ 16	−371	−387	....
21	2.50 p. m.	....	2551	1118	2435	2358	−1433	− 77	+1356	19. 0	+ 65	−302	−367	....
22	10.00 a. m.	U. S.	2543	1116	2452	2359	−1427	− 93	+1334	18. 8	+ 45	−318	−363	
22	11.00 a. m.	Pr.	2546	1117	2453	2351	−1429	−102	+1327	19. 7	− 12	−382	−370	−368
22	11.45 a. m.	U. S.	2552	1089	2456	2334	−1417	−122	+1341	20. 0	− 40	−407	−367	
22	3.10 p. m.	U. S.	2531	1086	2449	2353	−1445	− 96	+1349	19. 1	− 5	−377	−372	
July 2	9.45 a. m.	U. S.	2548	1077	2759	2642	−1471	−117	+1354	20. 2	− 322	−684	−362	−354
2	10.00 a. m.	U. S.	2549	1057	2755	2616	−1492	−139	+1353	21. 5	− 349	−695	−346	
														−361
BOTH THERMOMETER SCALES UP.														
June 25	10.00 a. m.	Pr.	2877	1458	2871	2755	−1419	−116	+1303	19. 6	− 31	+343	−374	
25	10.35 a. m.	U. S.	2869	1415	2872	2754	−1454	−118	+1336	19. 7	+ 2	+362	−360	−371
25	4.05 p. m.	Pr.	2838	1401	2933	2789	−1437	−144	+1293	19. 4	− 26	+342	−368	
26	9.55 a. m.	Pr.	2833	1427	2951	2813	−1406	−138	+1268	19. 3	− 91	+286	−377	.....
26	10.30 a. m.	U. S.	2831	1350	2939	2762	−1481	−177	+1304	19. 5	− 36	+322	−358	....
June 29	10.00 a. m.	U. S.	2838	1391	1829	1707	−1447	−122	+1325	19. 9	+ 87	+452	−365	....
29	10.20 a. m.	Pr.	2841	1387	1829	1694	−1454	−135	+1319	20. 1	+ 115	+495	−380	....
29	10.35 a. m.	U. S.	2838	1378	1824	1696	−1460	−128	+1332	20. 2	+ 125	+497	−372	−373
29	10.55 a. m.	Pr.	2835	1377	1820	1689	−1458	−131	+1327	20. 2	+ 138	+512	−374	
29	4.15 p. m.	U. S.	2842	1422	1823	1727	−1420	− 96	+1324	19. 7	+ 51	+435	−384	....
														−372
PRUSSIAN THERMOMETER SCALE UP, U. S. DOWN.														
June 23	10.30 a. m.	....	2887	1182	2788	2445	−1705	−343	+1362	20. 1	+ 111	−513	−402	−402
23	2.45 p. m.	....	2878	1212	2799	2478	−1666	−321	+1345	19. 8	+ 70	−472	−402	
24	10.20 a. m.	U. S.	2879	1204	2789	2479	−1675	−310	+1365	19. 7	+ 51	−429	−378	....
24	10.50 a. m.	Pr.	2879	1205	2786	2445	−1674	−341	+1333	19. 8	+ 74	−480	−406	....
24	4.20 p. m.	U. S.	2881	1211	2775	2466	−1670	−309	+1361	19. 7	+ 86	−473	−387	....
June 26	11.45 a. m.	U. S.	2841	1384	2830	2763	−1457	− 67	+1390	19. 6	+ 10	−466	−456	....
28	10.25 a. m.	U. S.	2833	1359	2824	2697	−1474	−127	+1347	19. 4	− 29	−360	−389	
28	10.45 a. m.	Pr.	2835	1349	2824	2688	−1486	−136	+1350	19. 5	− 12	−389	−401	−398
28	4.30 p. m.	....	2828	1392	2827	2719	−1436	−108	+1328	19. 1	− 54	−349	−403	
														−400
PRUSSIAN THERMOMETER SCALE DOWN, U. S. UP.														
June 30	10.00 a. m.	Pr.	2608	1180	1829	1689	−1428	−140	+1288	20. 6	− 181	+498	−317	
30	11.30 a. m.	U. S.	2603	1188	1805	1694	−1415	−111	+1304	21. 3	− 330	+638	−308	
30	0.20 p. m.	Pr.	2601	1179	1810	1679	−1422	−131	+1291	21. 2	− 315	+632	−317	−310
30	0.35 p. m.	U. S.	2599	1172	1811	1688	−1427	−123	+1304	21. 2	− 324	+629	−305	
30	3.25 p. m.	Pr.	2587	1197	1817	1708	−1390	−109	+1281	20. 5	− 215	+526	−311	
30	3.40 p. m.	U. S.	2615	1175	1824	1686	−1440	−138	+1302	20. 5	− 227	+532	−305	....
July 1	9.40 a. m.	Pr.	2608	1193	1821	1678	−1415	−143	+1272	20. 7	− 239	+554	−315	....
1	11.55 a. m.	U. S.	2539	1098	1736	1589	−1441	−147	+1294	21. 1	− 327	+618	−291	
1	0.10 p. m.	Pr.	2542	1084	1744	1572	−1458	−172	+1286	21. 2	− 333	+614	−281	−290
1	3.15 p. m.	U. S.	2547	1099	1741	1595	−1448	−146	+1302	21. 0	− 293	+585	−292	
1	3.30 p. m.	Pr.	2546	1086	1748	1583	−1460	−165	+1295	21. 0	− 306	+594	−288	
														−300

UNITED STATES COAST SURVEY.—COMPARISONS OF PRUSSIAN AND U. S. PENDULUM STANDARDS, 1877.

BOTH THERMOMETER SCALES DOWN.

Date.	Time.	Which first.	Prussian.		U. S.		Prussian *minus* comparator.	U. S. *minus* comparator.	U. S. *minus* Prussian.	Mean mercurial ther.	Prussian met. ther.	U. S. met. ther.	U. S. – Pr. ther.
			Below.	Above.	Below.	Above.							
										°			
Oct. 16	....	U. S.	2386	1603	1936	2478	− 783	+ 542	+1325	16. 2	−547	+291	+838
16	10.12 a. m.	Pr.	2379	1600	1938	2470	− 779	+ 532	+1311	16. 4	−571	+239	+810
16	10.35 a. m.	U. S.	2372	1591	1937	2466	− 781	+ 529	+1310	16. 7	−632	+216	+848
16	10.51 a. m.	Pr.	2363	1584	1931	2470	− 779	+ 539	+1318	16. 9	−645	+177	+822
16	11.23 a. m.	U. S.	2353	479	1886	1367	−1874	− 519	+1355	17. 2	−766	+ 30	+796
16	11.32 a. m.	Pr.	2374	486	1952	1386	−1888	− 566	+1322	17. 3	−769	+ 43	+812
16	11.58 a. m.	U. S.	2371	505	1951	1398	−1866	− 553	+1313	17. 2	−805	+ 26	+831
16	1.09 p. m.	U. S.	2482	1694	1879	2356	− 788	+ 477	+1265	17. 2	−805	+ 31	+836
16	1.16 p. m.	Pr.	2487	1686	1873	2364	− 801	+ 491	+1292	17. 1	−806	+ 44	+850
17	11.10 a. m.	Pr.	2434	1623	1887	2397	− 811	+ 510	+1321	16. 3	−596	+212	+808
17	11.20 a. m.	U. S.	2434	1608	1895	2379	− 826	+ 484	+1310	16. 3	−614	+199	+813
17	11.42 a. m.	Pr.	2421	1608	1888	2384	− 813	+ 496	+1309	16. 4	−671	+151	+822
17	11.53 a. m.	U. S.	2408	1610	1879	2395	− 798	+ 516	+1314	16. 3	−686	+137	+823

Results of comparisons between the pendulum-meter and No. 49, also between the pendulum itself and No. 49, have already been given, under the head of *Coefficient of Expansion*.

The result before given of comparison between the pendulum and No. 49 was obtained when the screws holding the knife-edge in place were tightly screwed up. With these screws loosened, the difference was at 10° C.

$$\text{Pendulum No. 49} = -\ 190^{\mu}.6,$$

the result before obtained being $-\ 199^{\mu}.5$ for 10° C. Neither result is of any value in determining the length of the pendulum.

The measures of length of the pendulum, as compared with the pendulum-meter, corrected for the value of micrometer-screw revolutions, reduced to heavy end down for the pendulum, and to metallic thermometer down and mean of lines 99.99, 100.00, and 100.01 of the meter, give for Pendulum *minus* U. S. pendulum-meter—

	μ
At Geneva..........	−198.7
At Paris..	−181.2
At Berlin	−177.1
At Kew..	−174.0
At Hoboken..	−165.1

The injury the pendulum received between the Geneva observations and those at Paris, and the work necessary to remedy this injury, account for the great discrepancy between the length at Geneva and that found elsewhere. Taking the remaining measures, however, their discordance will be seen to be far greater than can be accounted for by errors of observation, while the progressive character of this disagreement renders it unlikely that it is due to the greater tightness of the screws holding the knife-edges at one place than at another. It is no greater than may be probably ascribed to accumulations of oxide, &c., under the bearing surfaces of the knives. The comparisons in detail are given in the following tables:

UNITED STATES COAST SURVEY.—PENDULUM AT GENEVA.—LENGTH.

[Heavy end up is corrected by $+1\mu.0$ to bring it to heavy end down.]

Date. Heavy end (d.) down, or (u.) up.	ABOVE. Stand.	ABOVE. Pend.	P − St.	BELOW. Stand.	BELOW. Pend.	P − St.	Pend. longer than stand. uncorrected.	CORRECTION. Above.	CORRECTION. Below.	Corrected length.
										μ
Sept. 5 d.	2266	1661	−605	2101	3473	+1372	−1977	−2	+7	−198.6
d.	2219	1667	−542	2120	3599	+1479	−2021	−1	+7	−202.9
u.	2195	1675	−520	2117	3591½	+1474½	−1994½	−1	+7½	−199.3
u.	2185	1687	−498	2130	3628	+1498	−1996	−1	+7	−199.4
Sept. 6 u.	2250	1694	−556	2122	3595	+1473	−2029	−1	+7	−202.7
u.	2190	1690½	−499½	2131	3621	+1490	−1989½	−1	+7½	−198.8
d.	2195	1657	−538	2121	3552	+1431	−1969	−1	+7	−197.7
d.	2184	1687½	−496½	2126	3602½	+1476½	−1973	−1	+7	−198.1
Sept. 7 u.	2253	1677	−576	2134	3595½	+1461½	−2038	−1	+7	−203.6
8 u.	2239	1657½	−581½	2152	3588½	+1436½	−2018	−1	+7	−201.6
Sept. 9 d.	2257	1730	−527	2146	3581	+1435	−1962	−1	+7	−197.0
d.	2223	1723	−500	2170	3673	+1503	−2003	−1	+8	−201.2
u.	2210	1691	−519	2298	3748	+1450	−1969	−1	+7	−196.7
u.	2199	1707	−492	2317	3816½	+1499½	−1992	−1	+7	−199.0
Sept. 13 u.	2084	1234½	−849½	1708	2865½	+1157½	−2007	−2	+6	−200.5
u.	2036	1224	−812	1703	2877	+1174	−1986	−2	+6	−198.4
d.	2040	1258½	−781½	1725	2894½	+1169½	−1951	−2	+6	−195.9
d.	2072	1283	−789	1762	2915	+1153	−1942	−2	+6	−195.0
Sept. 14 u.	2149	1248	−901	1752	2812	+1060	−1961	−2	+5	−195.8
u.	2113	1263	−850	1733	2900	+1167	−2017	−2	+6	−201.5
d.	2101	1253	−848	1732	2812	+1080	−1928	−2	+5	−193.5
d.	2089	1257	−832	1747	2891	+1144	−1976	−2	+6	−198.4
Sept. 15 d.	2137	1275	−862	1739	2830	+1091	−1953	−2	+5	−196.0
d.	2119	1278	−841	1742	2887	+1145	−1986	−2	+6	−199.4
u.	2114	1276	−838	1738	2830	+1092	−1930	−2	+5	−192.7
u.	2113	1265	−848	1750	2898	+1148	−1996	−2	+6	−199.4
Sept. 16 d.	2140	1273½	−866½	1733	2853½	+1120½	−1987	−2	+6	−199.5
d.	2121	1265½	−855½	1742	2882½	+1140½	−1996	−2	+6	−200.4
u.	2122	1260½	−861½	1742	2853½	+1111½	−1973	−2	+6	−197.1
u.	2094	1263½	−830½	1737	2913½	+1176½	−2007	−2	+6	−200.5
Mean										−198.7

UNITED STATES COAST SURVEY.—PENDULUM AT PARIS.—LENGTH.

[Heavy end up is corrected by $+1\mu.0$ to bring it to heavy end down.]

Date. Heavy end (d.) down, and (u.) up.	ABOVE. Stand.	ABOVE. Pend.	P − St.	BELOW. Stand.	BELOW. Pend.	P − St.	Pend. longer than stand. uncorrected.	CORRECTION. Above.	CORRECTION. Below.	Corrected length.
1876.										μ
Jan. 25 u.	2373	1467	−906	1541	2444	+ 903	−1809	−3	+4	−180.6
u.	2378	1479	−899	1552	2413	+ 861	−1760	−3	+3	−175.6
d.	2356	1426	−930	1550	2365	+ 815	−1745	−3	+3	−175.1
d.	2367	1461	−906	1536	2400	+ 864	−1760	−3	+3	−176.6
Jan. 26 u.	2417	1451	−966	1558	2392	+ 834	−1800	−3	+3	−179.6
u.	2370	1445	−925	1547	2402	+ 855	−1780	−3	+3	−177.6
d.	2376	1437	−939	1554	2393	+ 839	−1778	−3	+3	−178.4
d.	2372	1459	−913	1547	2414	+ 867	−1780	−3	+3	−178.6
Jan. 28 d.	2400	1473	−927	1564	2406	+ 842	−1769	−3	+3	−177.5
d.	2363	1456	−907	1546	2391	+ 845	−1752	−3	+3	−175.8
u.	2374	1428	−946	1547	2387	+ 840	−1786	−3	+3	−178.2
Jan. 29 u.	2382	1433	−949	1554	2390	+ 836	−1785	−3	+3	−178.1
u.	2362	1401	−961	1539	2405	+ 866	−1827	−3	+3	−182.3
				Change of knife-edges.						
Feb. 2 u.	2093	1792	−301	1283	2815	+1532	−1833	−1	+6	−183.0
u.	2112	1832	−280	1278	2797	+1519	−1799	−1	+6	−179.6
d.	2132	1836	−296	1201	2779	+1488	−1784	−1	+6	−179.1
Feb. 3 d.	2148	1837	−311	1279	2787	+1508	−1819	−1	+6	−182.6
Feb. 4 d.	2144	1855	−289	1280	2812	+1532	−1821	−1	+6	−182.8
d.	2141	1854	−287	1274	2796	+1522	−1809	−1	+6	−181.6
u.	2140	1839	−301	1281	2812	+1531	−1832	−1	+6	−182.9
u.	2136	1847	−289	1280	2792	+1512	−1801	−1	+6	−179.8
				Change of knife-edges.						
Feb. 9 d.	2143	1844	−299	1268	2817	+1549	−1848	−1	+6	−185.5
d.	2153	1832	−321	1275	2801	+1526	−1847	−1	+6	−185.4
u.	2139	1844	−295	1272	2813	+1541	−1836	−1	+6	−183.3
u.	2138	1859	−279	1273	2826	+1553	−1832	−1	+6	−182.9
Feb. 14 u.	2130	1883	−247	1272	2883	+1611	−1858	−1	+6	−185.5
u.	2135	1868	−257	1274	2826	+1552	−1809	−1	+6	−180.6
d.	2336	1570	−766	1523	2523	+1000	−1766	−2	+4	−177.2
d.	2377	1592	−785	1537	2536	+ 999	−1784	−2	+4	−179.0
				Change of knife-edges.						
Feb. 21 d.	2405	1604	−801	1542	2550	+1008	−1809	−2	+4	−181.5
d.	2399	1603	−796	1531	2558	+1027	−1823	−2	+4	−182.9
u.	2388	1586	−802	1541	2544	+1003	−1805	−2	+4	−180.1
u.	2403	1606	−797	1542	2559	+1017	−1814	−2	+4	−181.0
Feb. 22 u.	2397	1593	−804	1545	2605	+1060	−1864	−2	+4	−186.0
u.	2383	1587	−796	1545	2547	+1002	−1798	−2	+4	−179.4
d.	2361	1591	−770	1544	2517	+ 973	−1743	−2	+4	−174.9
d.	2394	1597	−797	1544	2527	+ 983	−1780	−2	+4	−178.6
Mean										−180.3
Corrected for compression of standard										−181.2

UNITED STATES COAST SURVEY.—PENDULUM AT BERLIN.—LENGTH.

[Heavy end up corrected by $+1^{\mu}.0$ to bring it to heavy end down.]

Date.	Above. Stand.	Above. Pend.	P − St.	Below. Stand.	Below. Pend.	P − St.	Pend. longer than stand. uncorrected.	Correction. Above.	Correction. Below.	Corrected length.
1876.										μ
Apr. 19 d.	2293	1862	−431	1175	2487	+1312	−1743	0	+5	−174. 8
Apr. 20 d.	2247	1869	−378	1179	2490	+1311	−1689	0	+5	−169. 4
d.	2258	1869	−389	1174	2473	+1299	−1688	0	+5	−169. 3
u.	2245	1931	−314	1180	2526	+1346	−1660	0	+5	−165. 5
u.	2275	1897	−378	1180	2522	+1342	−1720	0	+5	−171. 5
Apr. 24 d.	2259	1879	−380	1165	2491	+1326	−1706	0	+5	−171. 1
d.	2248	1879	−369	1167	2496	+1329	−1698	0	+5	170. 3
u.	2239	1878	−361	1159	2518	+1359	−1720	0	+5	−171. 5
Apr. 25 d.	2257	1877	−380	1161	2595	+1434	−1814	rej.		
d.	2257	1895	−362	1159	2558	+1399	−1761	0	+6	−176. 7
u.	2224	1853	−371	1157	2540	+1383	−1754	0	+6	−175. 0
u.	2245	1878	−367	1162	2543	+1381	−1748	0	+6	−174. 4
Apr. 26 d.	2257	1881	−376	1161	2552	+1391	−1767	0	+6	−177. 3
d.	2257	1881	−376	1163	2538	+1375	−1751	0	+5	−175. 6
u.	2236	1872	−364	1164	2550	+1386	−1749	0	+6	−174. 5
u.	2244	1884	−360	1165	2560	+1395	−1755	0	+6	−175. 1
Apr. 28 u.	2266	1882	−384	1163	2562	+1399	−1783	0	+6	−177. 9
u.	2270	1872	−398	1160	2534	+1374	−1772	0	+5	−176. 7
d.	2276	1890	−386	1162	2567	+1405	−1791	0	+6	−179. 7
d.	2270	1895	−375	1167	2568	+1401	−1776	0	+6	−178. 2
Apr. 29 u.	2242	1870	−372	1157	2593	+1436	−1808	0	+6	−180. 4
u.	2226	1872	−354	1156	2577	+1421	−1775	0	+6	−177. 1
d.	2227	1882	−345	1156	2545	+1389	−1734	0	+6	−174. 0
d.	2247	1889	−358	1153	2558	+1405	−1763	0	+6	−176. 9
Apr. 30 u.	2248	1865	−383	1157	2608	+1451	−1834	0	+6	−183. 0
u.	2257	1865	−392	1156	2592	+1436	−1828	0	+6	−182. 4
d.	2233	1832	−401	1146	2533	+1387	−1788	0	+6	−179. 4
d.	2258	1869	−389	1159	2551	+1392	−1781	0	+6	−178. 7
May 2 u.	2272	1915	−357	1151	2646	+1495	−1852	0	+6	−184. 8
u.	2269	1914	−355	1150	2593	+1443	−1788	0	+6	−178. 4
May 3 d.	2262	1872	−390	1152	2603	+1451	−1841	0	+6	−184. 7
Mean										−176. 1
Corrected for compression of stand										−177. 1

UNITED STATES COAST SURVEY.—PENDULUM AT KEW.

[Four observations in parentheses rejected on account of temperature.
Heavy end up corrected by $+1^{\mu}.0$ to reduce to heavy end down.
All observations on mean of 9997th, 9998th, and 9999th lines corrected by $-200^{\mu}.4$ to reduce to mean of 9999th, 10000th, and 10001st.]

Date.	ABOVE.		P – St.	BELOW.		P – St.	Pend. longer than stand uncorrected.	CORRECTION.		Corrected length.
	Stand.	Pend.		Stand.	Pend.			Above.	Below.	
1876.										μ.
June 29 d.	(1936	2299	+363	1003	3124	+2121	−1758	−1	+7	−176.6)
30 d.	1950	......	......	......	......	......	......	......	......	......
d.	1924	2204	+280	1012	3016	+2004	−1724	−1	+7	−173.3
d.	1597	1609	+ 12	2684	2426	− 258	+ 270	0	−1	−173.3
d.	1605	1612	+ 7	2672	2405	− 267	+ 274	0	−1	−172.9
July 6 u.	1868	2697	+829	2733	3299	+ 566	+ 263	−2	+2	−173.1
u.	1781	1635	−145	2666	2246	− 420	+ 274	0	−1	−171.9
July 6 u.	1510	1652	+142	2370	2239	− 131	+ 273	0	0	−172.1
u.	1481	1631	+150	2360	2245	− 115	+ 265	0	0	−172.9
July 10...	(1580	1669	+ 89	2448	2337	− 111	+ 200	0	0	−180.4)
10...	(1536	1602	+ 66	2442	2294	− 148	+ 214	0	− 1	−178.9)
11...	(1515	1616	+101	2434	2307	− 127	+ 228	0	0	−177.6)
....	1476	1601	+125	2434	2291	− 143	+ 268	0	− 1	−173.5
....	1492	1624	+132	2435	2300	− 135	+ 267	0	0	−173.7
Mean										−173.0
Corrected for compression of stand										−174.0

UNITED STATES COAST SURVEY.—PENDULUM AT HOBOKEN.—LENGTH.

Date.	Obs.	ABOVE.		P—St.	BELOW.		P—St.	Pend. longer than stand. uncorrected.	Cor. below.	Corrected length.
		Stand.	Pend.		Stand.	Pend.				
1876.										μ
April 11	P.	2021	2517	+496	2116	2207	+ 91	+405	0	+40.5
11	P.	1985	2152	+167	2072	1884	−187	+354	0	+35.4
11	P.	1997	2142	+145	2062	1888	−174	+319	0	+31.9
12	S.	1975	2173	+198	2075	1831	−244	+442	+1	+44.1
12	S.	2011	2143	+132	2061	1834	−227	+359	+1	+35.8
12	S.	2014	2133	+119	2057	1811	−246	+365	+1	+36.4
13	S.	1980	2104	+124	2062	1818	−224	+368	+1	+36.7
13	S.	2004	2170	+166	2067	1838	−229	+395	+1	+39.4
13	S.	1995	2159	+164	2074	1839	−235	+399	+1	+39.8
14	S.	2004	2129	+125	2052	1815	−237	+362	+1	+36.1
14	S.	1993	2156	+163	2053	1810	−243	+406	+1	+40.5
14	S.	1995	2150	+155	2060	1813	−247	+402	+1	+40.1
16	S.	2028	2218	+190	2077	1882	−195	+385	0	+38.5
16	S.	2018	2217	+199	2071	1873	−198	+397	0	+39.7
16	S.	2020	2207	+187	2070	1877	−193	+380	0	+38.0
16	S.	2021	2213	+192	2067	1866	−201	+393	+1	+39.2
16	S.	2033	2222	+189	2081	1899	−182	+371	0	+37.1
17	S.	2029	2217	+188	2084	1892	−192	+380	0	+38.0
17	S.	2029	2207	+178	2073	1898	−175	+353	0	+35.3
23	S.	2035	2013	− 22	2034	1608	−426	+404	+1	+40.3
23	S.	2042	2017	− 25	2040	1613	−427	+402	+1	+40.1
23	P.	2695	2634	− 61	2750	2317	−433	+372	+1	+37.1
23	P.	2689	2646	− 43	2755	2326	−429	+386	+1	+38.5
23	P.	2023	1970	− 53	2037	1614	−423	+370	+1	+36.9
24	P.	2021	1965	− 56	2010	1604	−406	+350	+1	+34.9
24	P.	1959	1850	−109	1969	1506	−463	+354	+1	+35.3
24	P.	1956	1857	− 99	1115	1540	−435	+336	+1	+33.5
24	P.	1961	1855	−106	1981	1540	−441	+335	+1	+33.4
24	P.	1785	2059	+274	2121	2053	− 68	+342	0	+34.2
24	P.	1829	2091	+262	2133	2071	− 62	+324	0	+32.4
24	P.	1865	2140	+275	2135	2069	− 66	+341	0	+34.1
24	P.	2524	2814	+290	2855	2785	− 70	+369	0	+36.9
24	P.	2523	2811	+288	2829	2802	− 27	+315	0	+31.5
24	P.	1861	2134	+273	2143	2086	− 57	+330	0	+33.0
May 25	P.	2081	2431	+350	1649	1700	+ 51	+299	0	+29.9
25	P.	2083	2452	+369	1651	1709	+ 57	+311	0	+31.1
25	P.	2049	2444	+395	1636	1702	+ 66	+329	0	+32.9
25	P.	2060	2445	+385	1648	1698	+ 50	+335	0	+33.5
25	P.	2065	2457	+392	1639	1700	+ 61	+331	0	+33.1
25	P.	2058	2451	+393	1648	1690	+ 42	+351	0	+35.1
26	S.	1937	2302	+365	1479	1537	+ 58	+307	0	+30.7
26	S.	1907	2288	+381	1483	1541	+ 58	+323	0	+32.3
26	P.	1911	2289	+378	1551	1492	+ 59	+319	0	+31.9
26	P.	1884	2267	+383	1539	1478	+ 61	+322	0	+32.2
27	P.	1883	2147	+259	1964	1908	− 56	+315	0	+31.5
27	P.	1877	2143	+266	1953	1902	− 51	+317	0	+31.7
28	P.	2351	2182	−169	2412	1953	−459	+290	+1	+28.9
June 16	P.	1252	1526	+274	1532	1488	− 44	+318	0	+31.8
16	P.	1968	2501	+533	2238	2467	+229	+304	−1	+30.5
16	S.	1955	2529	+574	2231	2454	+223	+351	−1	+35.2
16	S.	1956	2511	+554	2230	2451	+221	+333	−1	+33.4
Mean										+35.3
Correction reducing to mean of 9999th, 10000th, and 10001st lines of pendulum-meter										−200.4
Length of pendulum										−165.1

CONCLUDED LENGTH OF THE PENDULUM.

The indirect comparisons of the U. S. pendulum-meter with the German meter No. 49 give the following result, when reduced to 15° C.:

	μ
U. S. meter — German pendulum-meter	+131.6
German pendulum-meter — No. 1605	−103.1
No. 1605 — No. 49	− 40.7
U. S. meter — No. 49	− 12.2
Direct comparison, U. S. meter — No. 49	− 20.0

The mean of these values, or $-16^{\mu}.1$, is taken, the likelihood of error of the two methods being estimated as equal. The bad temperature conditions at New York have prevented a more accurate determination of this quantity; but a new determination will be undertaken at the first opportunity.

But we have, for 15° C.:

$$\text{No. 49} - M = +\overset{\mu}{277.2}, \text{ hence}$$
$$\text{U. S. pendulum-meter} - M = +261.1$$

The length of the pendulum at the different stations is, therefore, as follows:

	cm.
Geneva	100.00624
Paris	100.00799
Berlin	100.00840
Kew	100.00871
Hoboken	100.00960

CENTER OF MASS.

The quantity $h_d - h_u$, or twice the distance of the center of mass of the pendulum from the center of figure, was observed at the beginning and end of each series of experiments, and also before and after each transposition of knife-edges. The apparatus, method of observing, etc., have been elsewhere described.* Comparisons at the U. S. Office of Weights and Measures show that the 39 centimeters on the staff of the balance, from 17 to 56, are 0.14 mm too long. This correction applied, we obtain for $h_d - h_u$,

	cm.
At Geneva	39.284
At other stations	39.292

These are the values used. The separate observations are shown in the following table:

* The idea of determining the center of mass of a reversible pendulum, instead of moving a weight upon it, belongs exclusively to Bessel.

UNITED STATES COAST SURVEY.—CENTER OF MASS OF REVERSIBLE PENDULUM.

GENEVA.

Date.	Knife at heavy end and direc'n of marked ends.	Firma.	HEAVY END. Reading in middle.	HEAVY END. Reading at end.	LIGHT END. Reading in middle.	LIGHT END. Reading at end.			$h_d - h_u$	Concluded. $h_d - h_u$
1875. Sept. 2	1 forward	Up	17068	01032	56037	00706	16036	55331	39295	39296
		Down	17069	01028½	56038	00701	16040½	55337	39297	
Sept. 2	2 forward	Up	16086	00049½	56039	00706½	16036¼	55332½	39296	39298
		Down	16086	00053½	56037	00704½	16032½	55332½	39300	
Sept. 3	2 forward	Up	16087	00046	56036	00701½	16031	55334½	39303½	39299
		Down	160·8	00045½	56037	00700½	16042½	55336½	39294	
Sept. 9	1 forward	Up	16040	00000½	56035	00695	16039½	55340	39300½	39301
		Down	16040	00001½	56034	00694¼	16038½	55339¼	39301	
Sept. 17	2 forward	Up	16046	00001	56028	00689	16045	55339	39294	39295
		Down	16045	00002½	56027	00688½	16042½	55338½	39296	
Mean at Geneva										39298

Between Geneva and Paris observations, the pendulum was bent and straightened, and the knife-edges were made parallel and ground.

PARIS.

Date.	Knife at heavy end and direc'n of marked ends.	Firma.	HEAVY END. Reading in middle.	HEAVY END. Reading at end.	LIGHT END. Reading in middle.	LIGHT END. Reading at end.			$h_d - h_u$	Concluded. $h_d - h_u$
1876. Jan. 22	1 forward	Up	17024	00977½	56051	00692½	16046½	55358½	39312	39310
		Down	....	00973½	....	00693	16050½	55358	39307½	
Jan. 29	1 forward	Up	17023	00975	56011	00656	16048	55355	39307	39306
		Down	17023	00971	....	00654¼	16052	55356½	39304½	
Jan. 29	2 forward	Up	17017	00959¼	56012	00650	16057½	55362	39304½	39305
		Down	....	00961	....	00651	16056	55361	39305	
Feb. 8	2 forward	Up	17018	00960	56054	00694	16058	55360	39302	39302
		Down	17017	00957	......	00692¼	16060	55361½	39301½	
Feb. 8	1 back	Up	17014	00960	56052	00696½	16054	55355¼	39301½	39302
		Down	....	00960	....	00696	16054	55356	39302	
Feb. 14	1 back	Up	17016	00961½	56050	00683¼	16054½	55366½	39312	39310
		Down	....	00960	....	00686½	16056	55363½	39307½	
Feb. 14	2 back	Up	17003	00947½	56050	00689	16055½	55361	39305½	39306½
		Down	....	00946	....	00685½	16057	55364½	39307½	
Feb. 24	2 back	Up	17003	00943	56055	00694	16060	55361	39301	39303
		Down	....	00947	....	00694¼	16056	55360½	39304½	
Mean at Paris										39306

CENTER OF MASS OF REVERSIBLE PENDULUM—Continued.

BERLIN

Date.	Knife at heavy end and direct'n of marked ends.	Firma.	HEAVY END. Reading in middle.	HEAVY END. Reading at end.	LIGHT END. Reading in middle.	LIGHT END. Reading at end.			$h_d - h_u$	Concluded. $h_d - h_u$
1876. Apr. 21	....	Up ...	17019	00962	56054	00679½	16057	55374½	39317½	39316
		Down ...	....	00960	....	00681	16059	55373	39314	
Apr. 24	1 forward .	Up	17019	00960	56028	00658½	16059	55369½	39310½	39310
		Down...	....	00959	....	00659	16060	55369	39309	
Apr. 27	2 forward .	Up	17009	00947	56030	00657½	16062	55372½	39310½	39312
		Down...	....	00945½	....	00653	16063½	55377	39313½	
Apr. 27	2 back	Up	17009	00947½	56040	00668	16061½	55372	39310½	39310
		Down ...	....	00946½	....	00668½	16062½	55371½	39309	
May 3	....	Up	16996	00931	56038	00669	16065	55369	39304	39300½
		Down...	....	00924½	....	00669½	16071½	55368½	39297	
June 3	1 back	Up	16996	00929½	56040	00671	16066½	55369	39302½	39303
		Down ...	....	00931½	....	00671½	16064½	55368½	39304	
June 3	2 back ...	Up	17014	00951	56040	00672	16063	55368	39305	39306
		Down ...	....	00951	....	00670	16063	55370	39307	
Mean at Berlin										39308

KEW.

Date.	Knife at heavy end and direct'n of marked ends.	Firma.	HEAVY END. Reading in middle.	HEAVY END. Reading at end.	LIGHT END. Reading in middle.	LIGHT END. Reading at end.			$h_d - h_u$	Concluded. $h_d - h_u$
1876. June 30	2..........	Up	17014	00938½	56044	00670	16075½	55374	39298½	39293
		Down...	....	00940½	....	00683	16073½	55361	39287¼	
July 6	2..........	Up	17004	00944¼	56045	00670½	16059½	55374½	39315	39316
		Down...	....	00946	....	00669½	16058	55375½	39317½	
July 6	1..........	Up	17004	00944½	56057	00688¼	16059½	55368½	39309	39307½
		Down ...	....	00953	....	00700	16051	55357	39306	
July 11	....	Up	16995	00930	56056	00692½	16063	55363½	39300½	39299½
		Down ...	....	00928½	....	00691	16066½	55365	39298½	
Mean at Kew										39304

HOBOKEN.

Date.	Knife at heavy end and direct'n of marked ends.	Firma.	HEAVY END. Reading in middle.	HEAVY END. Reading at end.	LIGHT END. Reading in middle.	LIGHT END. Reading at end.			$h_d - h_u$	Concluded. $h_d - h_u$
1877. Apr. 8	2 forward .	Up	16995	00933	56054	00687	16062	55367	39305	39300
		Down ...	....	00929	....	00693	16066	55361	39295	
June 17	2 forward .	Up	17054	00989	56050	00678	16065	55372	39307	39305
		Down...	....	00985	....	00678	16069	55372	39303	
1878. May 6	1 forward .	Up	17046	01003	56046	00686	16043	55360	39317	39313
		Down...	....	00995	....	00685	16051	55361	39310	
Mean at Hoboken										39306

PERIODS OF OSCILLATION AND VALUES OF GRAVITY.

The pendulum was swung in Hoboken in various ways, to wit:

1. The regular set was made on the Geneva support with the bells off. This set cannot be compared with others on the Repsold support, if the reductions be made on the principle of the reversible pendulum, owing to the different ways in which the knives rest on the two supports. The comparison may, however, be made on the principle of the invariable pendulum, so as to eliminate this effect.

2. Sets of experiments were made at various pressures on the Geneva support with the bells on. The knife-edges not having been interchanged, these are strictly only comparable among themselves.

3. Half a regular set was made on the Geneva support with the bells on at about 35° C. There were a few additional experiments at this temperature with heavy end up at different pressures.

4. The pendulum was swung on the Repsold support and also on a very stiff support having the head of the Repsold support as a part of it (so as to have the same bearing on the knives). The object of these experiments was to determine the effect of flexure of the support.

A conspectus of all these experiments is given in the following table:

Periods of oscillation of the pendulum at Hoboken; reduced to one absolute atmosphere and to 15° C., and to values on rigid support without bells or cylinder.

Heavy end down.					Heavy end up.					
Pressure.	Temp. C.	T_d	No. days.	No. thousand oscillations.	Pressure.	Temp. C.	T_u	No. days.	No. thousand oscillations.	
ON GENEVA SUPPORT.										
With bells on.—Regular set to determine gravity.—Knives interchanged.										
in.	°	*s.*			*in.*	°	*s.*			
30	20	1.006344	8	42	30	20	1.006537	8	18	
With bells on.—At high temperatures.										
in.	°	*s.*			*in.*	°	*s.*			
30	35	1.006346	4	22	30	35	1.006544	4	19	Knives interchanged.
					30	34	1.006530	2	6	Knife No. 1.
					2¼	38	1.006533	1	5	
					1¼	34	1.006521	1	2	
With bells on.—At various pressures.—Knife No. 1 at heavy end.										
in.	°	*s.*			*in.*	°	*s.*			
30	18	1.006349	3	16	30	10	1.006539	3	13	
					29	11	1.006560	2	7	
					27	10	1.006537	1	4	
					22½	11	1.006549	1	2	
15	18	1.006337	2	20	15	10	1.006545	1	3	
					7½	10	1.006533	2	10	
5	20	1.006336	1	15						
1½	20	1.006342	1	21						
					1	10	1.006524	1	11	
					¾	9	1.006530	4	53	
					4/10	9	1.006532	4	73	
ON REPSOLD SUPPORT.										
One day, knife No. 1 at heavy end; two days at light end.										
in.	°	*s.*			*in.*	°	*s.*			
30	14	1.006355	3	4	30	14	1.006516	3	4	
ON STIFFEST SUPPORT.										
Knife No. 1 at light end.										
in.	°	*s.*			*in.*	°	*s.*			
30	14	1.006366	1	2	30	15	1.006544	1	2	

The reductions in the above table have been made with the *à priori* constants of atmospheric effect, and with the coefficient of expansion, $18^{\mu}.38$ per degree Centigrade. A correction of $+ 73 \times 10$ for inequality of knives has been applied to the three last results with heavy end up at high temperatures.

The agreement of the several experiments of the regular set is shown by the following table of the observed periods (uncorrected for the effect of the cylinders and of flexure):

Hoboken.—Regular set.

	Obs. T_d	Obs. T_u
	s.	*s.*
	1.006352	1.006559
	352	560
	361	546
	360	558
	358	544
	350	539
	363	551
	356	534
Mean	1.006357	1.006548

The agreement of the several experiments of the half set at high temperatures is shown in the following table:

Hoboken.—Half set at high temperatures.

Obs. T_d	Obs. T_u
s.	*s.*
1.006533	1.006709
541	713
536	708
534	708
	706
	716
	708
	709

It will be seen that the mean results of the experiments of the regular set agree as well as could be expected with those made at high temperatures; which shows both that the coefficient of expansion is correct, and also that the correction for bell-glasses is happily not in error. Further to compare these two sets of experiments we may calculate the mean T^2 which is to be used when the reduction is made on the principle of the reversible pendulum, and also the mean T^2 which is to be used when the reduction is made on the principle of the invariable pendulum. Denoting the former by [T^2 Rev.] and the latter by [T^2 Inv.] we have algebraically

$$[T^2\ \text{Rev.}] = \frac{T_d^2\, h_d - T_u^2\, h_u}{h_d - h_u} \qquad [T^2\ \text{Inv.}] = \frac{T_d^2\, h_d + T_u^2\, h_u}{h_d + h_u}$$

The values will be

	[T^2 Inv.]	[T^2 Rev.]
	s^2	s^2
From regular set	1.012846	1.012410
From ½ set at high temperatures	1.012850	1.012399
Difference, in seconds, per day	$0^s.3$	$0^s.5$

We may next examine the experiments at various pressures. Their concordance with one another is very good; but the reader will hardly desire to see the single experiments set forth here; particularly as all the means are given in the tables at the end of this paper. We may exhibit [T^2 Inv.] and [T^2 Rev.] for pairs of experiments under nearly the same pressure but in reversed positions. But these results can have no value in the determination of gravity; nor can

they be expected to accord with those just obtained, for, not to speak of the non-interchange of knife-edges, the observations in the two positions were taken at intervals of months, under conditions very different in many respects, and were never intended to be used for obtaining gravity, but only to show the variation of the period and decrement of arc with the pressure.

	[T^2 Inv.]	[T^2 Rev.]
From experiments at 30 inches down and 30 inches up.....	1.012855$(s)^2$	1.012425$(s)^2$
From experiments at 15 inches down and 15 inches up.....	1.012842	1.012376
From experiments at 5 inches down and 7½ inches up.....	1.012832	1.012389
From experiments at 1½ inches down and 1 inch up.......	1.012836	1.012424
From mean of experiments at ½ and ¼ inch down and experiments at $\frac{4}{10}$ inch up..................................	1.012841	1.012415

The agreement is sufficient to show that the coefficient of atmospheric pressure is well determined.

We pass now to the experiments on the Repsold support and on the stiffest support. These were not very carefully made, being only intended to show that the effect of flexure was really what calculation had predicted. Upon these supports the knife-edge rested on steel instead of glass, and consequently the reductions on the principle of the reversible pendulum are not comparable with results of experiments on the Geneva support until the slip shall have been measured on both stands. The reductions on the principle of the invariable pendulum are, however, comparable.

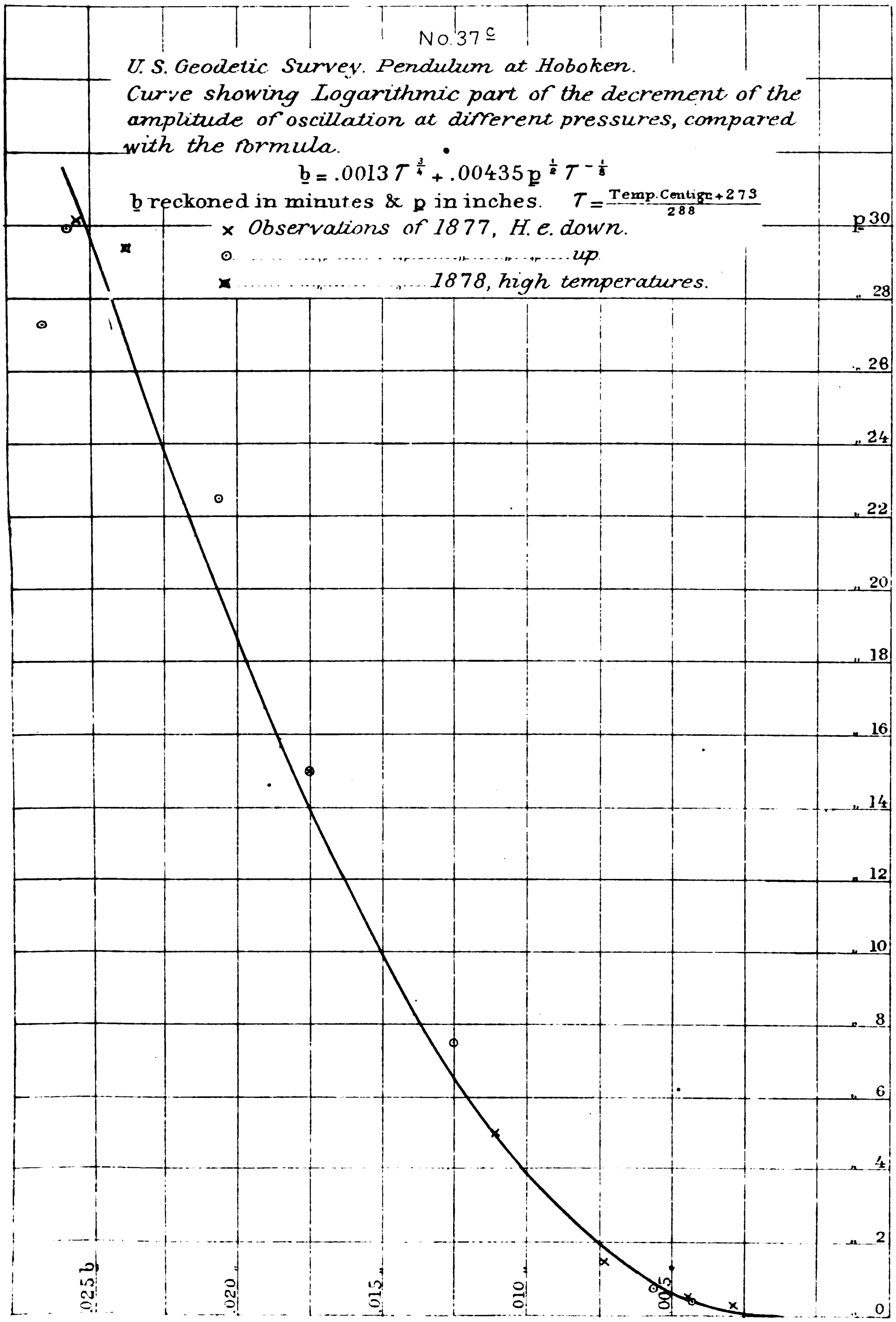
	[T^2 Inv.]	[T^2 Rev.]
From experiments on stiffest support	1.012879$(s)^2$	1.012512$(s)^2$
From experiments on Repsold support	1.012855	1.012514
From regular set	1.012846	
Δ Repsold and stiffest support, in seconds, per day.	$1^s.0$	$0^s.1$
Δ Repsold support and regular set	$0^s.6$	

We may now proceed to compare the results at the European stations. First, the results of the single experiments at each station will be compared, with only such corrections as vary from day to day. Next, the values of [T^2 Inv.] and [T^2 Rev.] will be given for each station after correcting them for the wear of the edges so as to reduce them to what they would have been for Paris, just after the knives had been ground. Lastly, we shall use the determinations by the principle of the reversible pendulum of the absolute length of the seconds' pendulum (still uncorrected for slip) at each station, in combination with the determinations of relative gravity on the principle of the invariable pendulum, in order to find four independent values of the length of the seconds' pendulum at each station. These, being corrected for elevation, will be comparable with the results of other experiments. The Hoboken experiments on the Geneva support cannot be used to determine [T^2 Rev.] until the slip has been ascertained; those made at Hoboken, on the Repsold support, must, therefore, be used in place of them for the present.

Paris.—Periods of oscillation.

	Heavy end down.	Heavy end up.
	s.	*s.*
	1.006051	1.006192
	048	210
	047	190
	048	195
	048	185
	052	185
	062	208
	053	213
Mean..........	1.006051	1.006197

The results on the last two days at Paris were affected by excessive damp.


No. 37 c
U. S. Geodetic Survey. Pendulum at Hoboken.
Curve showing Logarithmic part of the decrement of the amplitude of oscillation at different pressures, compared with the formula.
$b = .0013\,T^{\frac{3}{4}} + .00435\,p^{\frac{1}{2}}\,T^{-\frac{1}{8}}$
b reckoned in minutes & p in inches. $T = \frac{\text{Temp. Centigr.} + 273}{288}$
× Observations of 1877, H. e. down.
⊙ .... up.
⌘ .... 1878, high temperatures.
p 30
" 28
" 26
" 24
" 22
" 20
" 18
" 16
" 14
" 12
" 10
" 8
" 6
" 4
" 2
0
.025 b
.020
.015
.010
.005

Berlin.—Periods of oscillation.

	Heavy end down.	Heavy end up.
	s.	*s.*
	1.005899	1.006052
	901	037
	896	026
	890	036
	901	037
	896	034
	899	046
	895	034
Mean..........	1.005898	1.006038

Kew.—Periods of oscillation.

	Heavy end down.	Heavy end up.
	s.	*s.*
	1.005935	1.006077
	30	68
	29	73
	27	64
	25	70
	31	71
	28	64
	31	66
	29	70
	30	66
		59
		63
		72
		73
		66
		74
		77
		67
Mean..........	1.005930	1.006069

The following table shows the results of Paris, Berlin, and Kew in comparison:

	[T^2 Inv.]	[T^2 Rev.]	Diff.
Paris	1.0121042$(s)^2$	1.0116956$(s)^2$	4086
Berlin	1.0117925	1.0113934	3991
Kew	1.0118560	1.0114548	4012

These differences involve double the square roots of the sums of the squares of the errors of the periods of oscillation with heavy end down and with heavy end up. Therefore, the Berlin and Kew differences are remarkably close together, while that at Paris is rather divergent. The experiments at Hoboken show a wide discrepancy in this difference, owing to the use of the Geneva support. Consequently the [T^2 Rev.] cannot be used.

Now, reducing the values of [T^2 Rev.] to mean solar time and dividing into the length of our pendulum at Paris we obtain the length of the seconds' pendulum at the several stations. The ratios of the [T^2 Rev.] at the different stations, being inversely as the length of the seconds' pendulum, may be used to obtain the length of the seconds' pendulum at any station from the value

deduced from the [T^2 Rev.] at any other station. So that at each station we shall have not only a value of the seconds' pendulum deduced from the [T^2 Rev.] of that station but also two other values deduced from the [T^2 Rev.] of the two other stations. These three values will have nearly equal weight. They are as follows:

For Paris.	*m.*
From Paris observations	.9939390
From Berlin observations	02
From Kew observations	20
Mean	.9939337
Reduction to sea-level	+ 163
Seconds' pendulum at Paris reduced to sea-level	.9939500

For Berlin.	*m.*
From Paris observations	.9942362
From Berlin observations	.9942452
From Kew observations	.9942382
Mean	.9942399
Reduction to sea-level	+ 83
Seconds' pendulum at Berlin reduced to sea-level	.9942482

For Kew.	*m.*
From Paris observations	.9941757
From Berlin observations	.9941830
From Kew observations	.9941740
Mean	.9941776
Reduction to sea-level	+ 14
Seconds' pendulum at Kew reduced to sea-level	.9941790

No comparison can be attempted between these results and those of previous experimenters until the former have been corrected for the slip of the knives and the latter have been reduced anew according to modern methods. These matters will be treated in the second part of this report with results which will be found satisfactory.

The pendulum at Geneva was virtually a different pendulum from that used at the other stations, because of the accident that befel it after the Geneva experiments. These experiments can, therefore, only be reduced on the principle of the reversible pendulum. The concordance of the single experiments is shown in the following table:

GENEVA.

T_d^2	T_u^2
1.012599	1.012814
581	775
589	797
607	793
593	789
580	767
582	763
598	783

The resulting value of the length of the seconds' pendulum after correcting for flexure in the manner explained under that heading is

Length of seconds' pendulum at Geneva.

	m.
Experiments of Coast Survey	0.993556
Professor Plantamour's result	0.993550

The appended tables show the details of the experiments at the different stations.

Respectfully submitted.

C. S. PEIRCE,
Assistant.

UNITED STATES GEODETIC SURVEY.—PENDULUM AT PARIS, 1876.

HEAVY END DOWN.

Date.	Time of transit.	Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp.	Period, corrected.
	h. m. s.	*s.*								
Jan. 26	26 42.545									
	39 55.317	792.772	.045	792.727	788	1.0059987	+23	−79	+800	1.0060731
	3 41.846	1426.529	.042	1426.487	1418	59922	+23	−79	+796	662
	54 30.966	3049.120	.032	3049.088	3031	59644	+23	−79	+792	380
					(5237)					(1.0060509)
Jan. 28	36 04.848									
	49 17.572	792.724	.045	792.679	788	1.0059378	+23	−62	+788	1.0060127
	13 00.006	1422.514	.042	1422.472	1414	59915	+23	−62	+781	657
	3 57.273	3057.187	.031	3057.156	3039	59743	+23	−62	+776	480
					(5241)					(1.0060475)
Change of knife-edges, from No. 2 to No. 1.										
Feb. 2	49 57.380									
	3 6.109	788.729	.047	788.682	784	1.0059720	+23	−59	+766	1.0060450
	26 56.663	1430.554	.042	1430.512	1422	59859	+23	−59	+769	592
	17 44.781	3048.118	.032	3048.086	3030	59690	+23	−59	+769	423
					(5236)					(1.0060473)
Feb. 4	21 35.132									
	35 26.122	830.990	.047	830.943	826	1.0059843	+ 8	−25	+808	1.0060634
	58 24.349	1378.227	.040	1378.187	1370	59759	+ 8	−25	+806	548
	43 50.526	2726.177	.027	2726.150	2710	59594	+ 8	−25	+815	392
					(4906)					(1.0060477)
Change of knife-edges, from No. 1 to No. 2.										
Feb. 9	42 04.281									
	56 09.340	845.059	.049	845.010	840	1.0059642	+ 8	−15	+852	1.0060487
	19 09.561	1380.221	.042	1380.179	1372	59613	+ 8	−15	+845	451
	11 36.262	3146.701	.035	3146.666	3128	59674	+ 8	−15	+830	497
					(5340)					(1.0060484)
Feb. 14	22 51.895									
	36 55.946	844.051	.052	843.999	839	1.0059583	+ 8	−09	+765	1.0060347
	59 57.201	1381.255	.043	1381.212	1373	59811	+ 8	−09	+760	570
	55 45.135	3347.934	.036	3347.898	3328	59790	+ 8	−09	+756	545
					(5540)					(1.0060521)
Change of knife-edges, from No. 2 to No. 1.										
Feb. 21	18 49.010									
	35 29.053	1000.043	.056	999.987	994	1.0060231	+ 8	−41	+475	1.0060673
	55 51.888	1222.835	.035	1222.800	1215½	60054	+ 8	−41	+475	496
	48 50.446	3178.558	.035	3178.523	3159½	60209	+ 8	−41	+469	645
					(5369)					(1.0060617)
Feb. 22	48 01.742									
	03 15.250	913.508	.054	913.454	908	1.0060066	+ 8	−36	+400	1.0060438
	28 4.196	1488.946	.043	1488.903	1480	60155	+ 8	−36	+402	529
	18 38.379	3034.183	.032	3034.151	3016	60182	+ 8	−36	+400	554
					(5404)					(1.0060528)

PENDULUM AT PARIS, 1876—Continued.

HEAVY END UP.

Date.	Time of transit.		Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp.	Period, corrected.
	h. m.	s.	s.								
Jan. 26	33	30.148									
	38	20.301	350.153	.017	350.136	348	1.0061379	+23	−183	+692	1.0061911
	49	42.111	621.810	.018	621.792	618	61359	+23	−183	+690	1889
	11	52.245	1330.134	.015	1330.119	1322	61415	+23	−183	+685	1940
						(2288)					(1.0061922)
Jan. 29	27	10.797									
	32	56.946	346.149	.020	346.129	344	1.0061899	+23	−152	+640	2410
	43	22.790	625.844	.019	625.825	622	61500	+23	−152	+639	2010
	06	45.096									
	28	57.261	1332.166	.014	1332.151	1324	1.0061563	+23	−152	+631	2065
						(2290)					(1.0062102)
Change of knife-edges, from No. 1 to No. 2.											
Feb. 2	42	06.507									
	47	52.620	346.113	.021	346.092	344	1.0060814	+23	−127	+616	1326
	58	20.449	627.829	.019	627.810	624	61058	+23	−127	+614	1568
	20	28.601	1327.152	.015	1327.137	1319	61692	+23	−127	+614	2202
						(2287)					(1.0061897)
Feb. 4	37	42.973									
	43	50.238	368.265	.021	368.244	366	1.0061311	+08	−050	+641	1910
	53	51.932	601.694	.019	601.675	598	61455	+08	−050	+648	2061
	14	5.338	1213.406	.014	1213.392	1206	61294	+08	−050	+649	1901
						(2170)					(1.0061946)
Change of knife-edges, from No. 2 to No. 1.											
Feb. 9	15	38.392									
	21	46.660	368.268	.023	368.245	366	1.0061339	+08	−031	+690	2006
	31	50.357	603.697	.018	603.679	600	61317	+08	−031	+681	1975
	54	54.778	1384.421	.015	1384.406	1376	61090	+08	−031	+682	1749
						(2342)					(1.0061847)
Feb. 14	57	20.800									
	3	27.026	366.226	.024	366.202	364	1.0060494	+08	−017	+685	1170
	13	40.787	613.761	.017	613.744	610	61377	+08	−017	+685	2053
	37	49.623	1448.836	.015	1448.821	1440	61257	+08	−017	+683	1931
						(2414)					(1.0061847)
Change of knife-edges, from No. 1 to No. 2.											
Feb. 21	9	17.620									
	16	01.129	403.509	.024	403.485	401	1.0061930	+08	−090	+389	2237
	25	41.719	580.590	.017	580.573	577	61924	+08	−090	+389	2231
	47	33.776	1312.057	.017	1312.040	1304	61656	+08	−090	+389	1963
						(2282)					(1.0062078)
Feb. 22	42	43.316									
	49	23.814	400.498	.024	400.474	398	1.0062161	+08	−087	+376	2458
	59	17.467	593.653	.018	593.635	590	61610	+08	−087	+373	1904
	21	13.570	1316.103	.014	1316.089	1308	61842	+08	−087	+368	2131
						(2296)					(1.0062129)

UNITED STATES COAST SURVEY.—PENDULUM AT BERLIN, 1876.

HEAVY END DOWN.

Date.	Time of transit.	Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp.	Period, corrected.
	h. m. s.	s.								
Apr. 20	7 46 6.276									
	8 00 27.356	861.080	.051	861.029	856	1.0058750	− 20	−05	+235	1.0058960
	25 22.154	1494.798	.044	1494.754	1486	58910	− 20	−05	+229	9114
	9 15 45.845	3023.691	.032	3023.659	3006	58744	− 20	−05	+219	8938
					(5348)					(1.0058990)
Apr. 24	7 58 29.726									
	8 12 56.855	867.429	.050	867.079	862	1.0058853	− 05	−50	+163	1.0058961
	8 37 11.415	1454.560	.043	1454.517	1446	58900	− 05	−50	+154	8999
	9 26 50.885	2979.470	.032	2979.438	2962	58872	− 05	−50	+141	8958
					(5270)					(1.0059011)
				Change of knife-edges, from No. 2 to No. 1.						
Apr. 25	7 52 42.427									
	8 5 34.992	772.565	.046	772.519	768	1.0058841	+ 20	−47	+133	1.0058947
	8 31 10.033	1535.041	.046	1534.995	1526	58945	+ 20	−47	+127	9045
	9 22 11.466	3061.433	.032	3061.401	3043½	58817	+ 20	−47	+120	8910
					(5337½)					(1.0058954)
Apr. 26	7 24 10.687									
	7 39 9.489	898.802	.053	898.749	893½	1.0058747	+ 20	−44	+160	1.0058883
	8 03 22.545	1453.056	.043	1453.013	1444½	58934	+ 20	−44	+153	9063
	8 53 58.330	3035.785	.032	3035.753	3018	58824	+ 20	−44	+135	8935
					(5356)					(1.0658959)
Apr. 28	9 55 51.699									
	10 10 35.938	884.239	.052	884.187	879	1.0059011	− 20	−18	+117	1.0059090
	10 35 1.069	1465.131	.043	1465.088	1456½	58963	− 20	−18	+110	9035
	11 26 23.675	3082.606	.033	3082.573	3064½	58949	− 20	−18	+103	9014
					(5400)					(1.0059031)
Apr. 29	10 4 4.873									
	10 19 11.260	906.387	.053	906.334	901	1.0059201	− 24	00	+077	1.0059254
	10 44 35.226	1523.966	.044	1523.922	1515	58891	− 24	00	+072	8939
	11 33 55.599	2960.373	.032	2960.341	2943	58923	− 24	00	+069	8968
					(5359)					(1.0059007)
				Change of knife-edges, from No. 1 to No. 2.						
Apr. 30	9 48 32.618									
	10 3 18.235	885.617	.052	885.565	880½	1.0057524	+1266	−09	+078	1.0058857
	10 27 33.128	1454.893	.043	1454.850	1446½	57726	+1266	−09	+074	9057
	11 17 49.445	3016.317	.032	3016.285	2999	57636	+1266	−09	+072	8965
					(5326)					(1.0058970)
May 2	10 9 4.306									
	10 23 33.445	869.139	.051	869.088	864	1.0058889	− 20	−24	+078	1.0058923
	10 47 48.008	1454.563	.043	1454.520	1446	58921	− 20	−24	+076	8953
	10 37 29.499	2981.491	.032	2981.459	2964	58904	− 20	−24	+070	8930
					(5274)					(1.0058934)

PENDULUM AT BERLIN, 1876—Continued.

HEAVY END UP.

Date.	Time of transit.	Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp.	Period, corrected.
	h. m. s.	s.								
Apr. 20	10 39 53.808									
	45 21.794	327.986	.018	327.968	326	1.0060368	−20	− 13	+158	1.0060493
	55 55.608	633.814	.019	633.795	630	60238	−20	− 13	+158	60363
	11 17 55.051	1319.443	.014	1319.429	1311½	60458	−20	− 13	+157	60582
					(2267½)					
Apr. 24	10 39 34.322									
	44 44.200	309.878	.017	309.861	308	1.0060422	−05	−114	+102	1.0060405
	55 42.192	657.992	.020	657.972	654	60734	−05	−114	+101	60716
	11 18 22.348	1360.156	.014	1360.142	1352	60240	−05	−114	+098	60219
					(2314)					
Change of knife-edges, from No. 1 to No. 2.										
Apr. 25	10 40 17.215									
	46 13.008	295.793	.020	295.773	294	1.0060306	+20	−106	+081	1.0060301
	57 10.481	656.473	.020	657.453	653½	60490	+20	−106	+080	60484
	11 19 31.024	1340.543	.014	1340.529	1332½	60255	+20	−106	+079	60248
					(2280)					
Apr. 26	10 24 38.854									
	29 50.246	311.392	.017	311.375	309½	1.0060582	+20	− 89	+089	1.0060602
	40 46.193	655.947	.020	655.927	652	60230	+20	− 89	+088	60249
	11 3 16.807	1350.614	.014	1350.600	1342½	60335	+20	− 89	+086	60352
					(2304)					
Apr. 28	7 26 20.727									
	31 12.494	291.767	.017	291.750	290	1.0060345	−20	− 52	+144	1.0060417
	42 45.149	692.655	.021	692.634	688½	60044	−20	− 52	+139	60111
	8 5 17.247	1352.098	.014	1352.084	1344	60141	−20	− 52	+131	60200
					(2322½)					
Apr. 29	7 49 31.597									
	55 27.757	356.160	.020	356.140	354	1.0060452	−24	− 03	+098	1.0060523
	8 5 47.463	619.706	.018	619.688	616	59870	−24	− 03	+095	59938
	28 19.558	1352.095	.014	1352.081	1344	60126	−24	− 03	+091	60190
					(2314)					
Change of knife-edges, from No. 2 to No. 1.										
Apr. 30	7 58 1.799									
	8 3 17.204	315.405	.018	315.387	313½	1.0060191	−15	− 06	+097	1.0060267
	13 51.007	633.803	.018	633.785	630	60079	−15	− 06	+095	60153
	35 46.924	1315.917	.014	1315.903	1308	60420	−15	− 06	+088	60487
					(2251½)					
May 2	8 9 14.734									
	14 24.588	309.854	.017	309.837	308	1.0059643	−20	− 48	+081	1.0059656
	25 6.451	641.863	.019	641.844	638	60251	−20	− 48	+080	60263
	46 46.262	1299.811	.013	1299.798	1292	60356	−20	− 48	+077	60365
					(2238)					

UNITED STATES GEODETIC SURVEY.—PENDULUM AT BERLIN, 1876.—SECOND READING OF FILLETS.

HEAVY END DOWN.

Date.	Time of transit.	Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp.	Period, corrected.
	h. m. s.	s.								
Apr. 20	7 46 6.276									
	8 0 25.843	859.067	.051	859.016	854	1.0058735	− 20	−05	+235	1.0058945
	8 25 22.154	1496.811	.044	1496.767	1488	58918	− 20	−05	+229	9122
	9 15 45.846	3023.692	.032	3023.660	3006	58749	− 20	−05	+219	8943
					(5348)					(1.0058993)
Apr. 24	7 58 29.727									
	8 12 56.855	867.128	.050	867.078	862	1.0058910	− 05	−50	+163	1.0059018
	8 37 11.417	1454.562	.043	1454.519	1446	58914	− 05	−50	+154	9013
	9 26 50.882	2979.465	.032	2979.433	2962	58855	− 05	−50	+141	8941
					(5270)					(1.0059017)
Apr. 25	7 52 42.430									
	8 5 34.999	772.569	.046	772.523	768	1.0058893	+ 20	−47	+133	1.0058999
	8 31 .030	1535.031	.046	1534.985	1526	58879	+ 20	−47	+127	8979
	9 22 11.470	3061.440	.032	3061.408	3043½	58840	+ 20	−47	+120	8933
					(5337½)					(1.0058956)
Apr. 26										
Apr. 28	9 55 52.194									
	10 10 35.934	883.740	.052	883.688	878½	1.0059055	− 20	−18	+117	1.0059134
	10 35 1.062	1465.128	.043	1465.085	1456½	58942	− 20	−18	+110	9014
	11 26 23.673	3082.611	.033	3082.578	3064½	58992	− 20	−18	+103	9057
					(5399½)					(1.0059058)
Apr. 29	10 4 4.892									
	10 19 11.260	906.368	.053	906.315	901	1.0058990	− 24	00	+077	1.0059043
	10 44 35.225	1523.965	.044	1523.921	1515	58884	− 24	00	+072	8932
	11 33 55.598	2960.373	.032	2960.341	2943	58923	− 24	00	+069	8968
					(5359)					(1.0058969)
Apr. 30	9 48 32.615									
	10 3 18.248	885.633	.052	885.581	880½	1.0057706	+1266	−09	+078	1.0059041
	10 27 33.126	1454.878	.043	1454.835	1446½	57691	+1266	−09	+074	9022
	11 17 49.446	3016.330	.032	3016.288	2999	57646	+1266	−09	+072	8975
					(5326)					(1.0058997)
May 2	10 9 4.303									
	10 23 33.441	869.138	.051	869.087	864	1.0058877	− 20	−24	+078	1.0058911
	10 47 48.007	1454.566	.043	1454.523	1446	58942	− 20	−24	+076	8974
	11 37 29.497	2981.490	.032	2981.458	2964	58900	− 20	−24	+070	8926
					(5274)					(1.0058936)

PENDULUM AT BERLIN, 1876.—SECOND READING OF FILLETS—Continued.

HEAVY END UP.

Date.	Time of transit.	Intervals.	Cor. for arc	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp.	Period, corrected.
	h. m. s.	*s.*								
Apr. 20	10 39 53.808									
	10 45 21.795	327.987	.018	327.969	326	1.0060399	−20	− 13	+158	1.0060524
	10 55 55.606	633.811	.019	633.796	630	60254	−20	− 13	+158	60379
	11 17 55.056	1319.450	.014	1319.432	1311½	60480	−20	− 13	+157	60604
					(2267½)					
Apr. 24	10 39 34.319									
	10 44 44.199	309.880	.017	309.863	308	1.0060427	− 5	−114	+102	1.0060410
	10 55 42.186	657.987	.020	657.967	654	60657	− 5	−114	+101	60639
	11 18 22.345	1360.159	.014	1360.145	1352	60244	− 5	−114	+ 98	60223
					(2314)					
Apr. 25	10 40 17.219									
	10 46 13.007	295.788	.020	295.768	294	1.0060186	+20	−106	+ 81	1.0060131
	10 57 10.480	657.473	.020	657.453	653½	60490	+20	−106	+ 80	60484
	11 19 31.001	1340.521	.014	1340.507	1332½	60090	+20	−106	+ 79	60083
					(2280)					
Apr. 26	....									
	....	....	....	....	....	....	....	....	....	....
	....	....	....	....	....	....	....	....	....	....
	....	....	....	....	....	....	....	....	....	....
Apr. 28	7 76 20.728									
	7 31 12.491	291.763	.017	291.746	290	1.0060207	−20	− 52	+144	1.0060279
	7 42 45.140	692.649	.021	692.628	688½	59956	−20	− 52	+139	60023
	8 5 17.248	1352.108	.014	1352.094	1344	60223	−20	− 52	+131	60282
					(2322½)					
Apr. 29	7 49 31.594									
	7 55 27.735	356.141	.020	356.121	354	1.0059915	−24	− 3	+ 98	1.0059986
	8 5 47.463	619.728	.018	619.710	616	60227	−24	− 3	+ 95	60295
	8 28 19.558	1352.095	.014	1352.081	1344	60126	−24	− 3	+ 91	60190
					(2314)					
Apr. 30	7 58 1.801									
	8 3 17.204	315.403	.018	315.385	313½	1.0060128	−15	− 6	+ 97	1.0060204
	8 13 51.007	633.803	.018	633.785	630	60079	−15	− 6	+ 95	60153
	8 35 46.925	1315.918	.014	1315.904	1308	60428	−15	− 6	+ 88	60495
					(2251½)					
May 20	8 9 14.732									
	8 14 24.593	309.861	.017	309.844	308	1.0059870	−20	− 48	+ 81	1.0059883
	8 25 6.441	641.848	.019	641.829	638	60016	−20	− 48	+ 80	60028
	8 46 46.260	1299.819	.013	1299.806	1292	60418	−20	− 48	+ 77	60427
					(2238)					

UNITED STATES COAST SURVEY.—PENDULUM AT KEW, JULY, 1876.

HEAVY END DOWN.

Date.	Method.	Time of transit.	Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp.	Period, corrected.
		h. m. s.	s.								
July 1	A	10 21 7.884									
	D	10 36 32.320	924.436	.055	924.381	919	1.0058552	+1269	−41	−293	1.0059487
	D	11 2 46.510	1574.190	.045	1574.145	1565	58435	+1269	−41	−296	367
	D	11 51 56.675	2950.165	.029	2950.136	2933	58425	+1269	−41	−298	355
						(5417)					(1.0059881)
July 2	D	6 42 58.365									
	C	6 58 35.845	937.480	.054	937.426	932	1.0058219	+1281	−50	−291	1.0059159
	C	7 21 52.006	1396.161	.041	1396.120	1388	58501	+1281	−50	−300	432
	B	8 12 44.764	3052.758	.032	3052.726	3035	58405	+1281	−50	−305	331
						(5355)					(1.0059328)
July 3	A	6 52 30.199									
	D	7 10 46.638	1096.439	.059	1096.380	1090	1.0058532	+1275	−60	−329	1.0059418
	A	7 31 19.845	1233.207	.035	1233.172	1226	58499	+1275	−60	−333	381
	A	8 21 53.837	3098.992	.033	3093.959	3076	58384	+1275	−60	−334	265
						(5392)					(1.0059322)
July 4	B	8 47 30.365									
	D	6 2 52.780	922.415	.053	922.362	917	1.0058473	+1271	−53	−311	1.0059380
	A	6 26 30.049	1417.269	.042	1417.227	1409	58389	+1271	−53	−322	285
	A	7 17 51.973	3081.924	.032	3081.892	3064	58394	+1271	−53	−328	284
						(5390)					(1.0059301)
July 4	B	10 9 10.507									
	A	10 24 41.982	931.475	.053	931.422	926	1.0058553	+1271	−51	−334	1.0059439
	B	10 48 10.172	1408.190	.042	1408.148	1400	58200	+1271	−51	−333	087
	B	11 40 42.517	3152.345	.033	3152.312	3134	58430	+1271	−51	−329	321
						(5460)					(1.0059281)
					Change of knife-edges, from No. 1 to No. 2.						
July 7	D	6 25 10.062									
	B	6 40 30.456	920.394	.052	920.342	915	1.0058383	+1297	−29	−330	1.0059321
	C	7 4 35.883	1445.427	.042	1445.385	1437	58351	+1297	−29	−342	277
	C	7 56 21.945	3106.062	.033	3106.529	3088	58384	+1297	−29	−357	295
						(5440)					(1.0059295)
July 7	B	10 31 28.644									
	B	10 47 16.214	947.570	.054	947.516	942	1.0058556	+1297	−26	−388	1.0059439
	B	11 11 18.607	1442.393	.042	1442.351	1434	58236	+1297	−26	−388	119
	D	12 4 26.142	3186.535	.033	3186.502	3168	58403	+1297	−26	−386	288
						(5544)					(1.0059270)
July 8	B	6 28 6.506									
	A	6 43 50.039	943.533	.055	943.478	938	1.0058400	+1310	−22	−342	1.0059346
	B	7 7 46.412	1436.373	.042	1436.331	1428	58340	+1310	−22	−345	283
	B	7 59 32.460	3106.048	.033	3106.015	3088	58339	+1310	−22	−346	281
						(5454)					(1.0059293)
July 9	B	7 16 52.359									
	A	7 32 33.873	941.514	.054	941.460	936	1.0058333	+1287	−43	−318	1.0059259
	B	7 56 32.249	1438.376	.042	1438.334	1430	58280	+1287	−43	−325	199
	B	8 48 46.480	3134.231	.032	3134.199	3116	58405	+1287	−43	−330	319
						(5482)					(1.0059277)
July 10	D	7 22 39.981									
	D	7 38 20.486	940.505	.054	940.451	935	1.0058299	+1300	−50	−255	1.0059294
	B	8 3 34.305	1513.819	.043	1513.776	1505	58312	+1300	−50	−261	301
	A	8 53 51.827	3017.522	.032	3017.490	3000	58300	+1300	−50	−269	281
						(5440)					(1.0059289)

PENDULUM AT KEW, JULY, 1876—Continued.

HEAVY END UP.

Date.	Method.	Time of transit.	Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp.	Period, corrected.
		h. m. s.	s.								
July 1	....	12 4 38.635									
	....	12 10 35.776	357.141	.020	357.121	355	1.0059746	+1269	− 92	−248	1.0060675
	....	12 22 3.866	688.090	.020	688.070	684	59503	+1269	− 92	−251	429
	....	12 43 40.584	1296.718	.013	1296.705	1289	59775	+1269	− 92	−253	699
						(2328)					(1.0060612)
July 2	....	5 12 52.612									
	....	5 19 54.123	421.511	.019	421.492	419	1.0059475	+1281	−114	−213	1.0060429
	....	5 30 29.920	635.797	.017	635.780	632	59810	+1281	−114	−221	756
	....	5 53 52.226	1402.306	.013	1402.293	1394	59491	+1281	−114	−226	432
						(2445)					(1.0060515)
July 2	....	8 26 28.214									
	....	8 32 50.506	382.292	.021	382.271	380	1.0059763	+1281	−117	−263	1.0060664
	....	8 42 56.119	605.613	.018	605.595	602	59718	+1281	−117	−269	613
	....	9 5 38.207	1362.088	.014	1362.074	1354	59631	+1281	−117	−272	523
						(2336)					(1.0060569)
July 3	....	5 36 32.199									
	....	5 42 50.446	378.247	.022	378.225	376	1.0059176	+1275	−140	−243	1.0060068
	....	5 53 32.262	641.816	.019	641.797	638	59514	+1275	−140	−248	401
	....	6 16 20.400	1368.138	.014	1368.124	1360	59755	+1275	−140	−257	633
						(2374)					(1.0060481)
July 3	....	9 39 10.524									
	....	9 45 43.885	393.361	.023	393.338	391	1.0059795	+1275	−133	−284	1.0060653
	....	9 56 00.545	616.660	.018	616.642	613	59413	+1275	−133	−287	268
	....	10 19 1.766	1381.221	.014	1381.207	1373	59774	+1275	−133	−291	625
						(2377)					(1.0060538)
July 4	....	4 45 55.609									
	....	4 52 31.981	396.372	.023	396.349	394	1.0059619	+1271	−126	−232	1.0060532
	....	5 3 15.808	643.827	.019	643.808	640	59500	+1271	−126	−237	408
	....	5 26 34.123	1398.315	.014	1398.301	1390	59717	+1271	−126	−247	615
						(2424)					(1.0060547)
July 4	....	7 35 40.095									
	....	7 42 16.473	396.378	.022	396.356	394	1.0059797	+1271	−119	−274	1.0060675
	....	7 52 12.002	595.529	.017	595.512	592	59324	+1271	−119	−276	200
	....	8 15 6.168	1374.166	.015	1374.151	1366	59671	+1271	−119	−278	545
						(2352)					(1.0060480)
July 4	....	9 5 28.179									
	....	9 12 10.591	402.412	.023	402.389	400	1.0059725	+1271	−118	−269	1.0060609
	....	9 22 30.259	619.668	.018	619.650	616	59253	+1271	−118	−271	135
	....	9 45 32.484	1382.225	.014	1382.211	1374	59752	+1271	−118	−274	631
						(2390)					(1.0060499)
July 4	....	12 2 46.318									
	....	12 9 18.675	392.357	.023	392.334	390	1.0059846	+1271	−114	−273	1.0060730
	....	12 19 48.451	629.776	.019	629.757	626	60016	+1271	−114	−275	898
	....	12 42 28.501	1360.050	.014	1360.036	1352	59438	+1271	−114	−276	319
						(2368)					(1.0060540)

PENDULUM AT KEW, JULY, 1876—Continued.

HEAVY END UP—Continued.

Date.	Method.	Time of transit.	Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp.	Period, corrected.
				Change of knife-edges, from No. 2 to No. 1.							
		h. m. s.	s.								
July 7	A	5 22 10.009									
	B	5 28 34.302	383.293	.022	383.271	381	1.0059606	+1297	− 68	−247	1.0060588
	A	5 39 4.045	629.743	.019	629.724	626	59488	+1297	− 68	−253	464
	A	6 1 21.989	1337.944	.014	1337.930	1330	59624	+1297	− 68	−264	589
						(2337)					(1.0060555)
July 7	D	8 40 40.053									
	D	8 47 14.392	394.339	.023	394.316	392	1.0059082	+1297	− 64	−304	1.0060011
	D	8 57 56.216	641.824	.019	641.805	638	59639	+1297	− 64	−308	564
	D	9 20 52.395	1376.179	.015	1376.164	1368	59673	+1297	− 64	−314	592
						(2398)					(1.0060490)
July 7	B	9 30 20.421									
	B	9 37 0.814	400.393	.023	400.370	398	1.0059548	+1297	− 63	−320	1.0060462
	B	9 47 32.548	631.734	.019	631.715	628	59156	+1297	− 63	−321	069
	B	10 10 10.642	1358.094	.014	1358.080	1350	59852	+1297	− 63	−322	764
						(2376)					(1.0060530)
July 7	C	12 22 54.115									
	D	12 29 22.447	388.332	.022	388.310	386	1.0059845	+1297	− 56	−323	1.0060763
	D	12 40 16.361	653.914	.020	653.894	650	59908	+1297	− 56	−324	825
	D	13 2 52.405	1356.044	.014	1356.030	1348	59570	+1297	− 56	−325	486
						(2384)					(1.0060623)
July 8	C	5 21 29.981									
	D	5 28 2.341	392.360	.023	392.337	390	1.0059923	+1310	− 47	−265	1.0060921
	D	5 38 48.184	645.843	.020	645.823	642	59548	+1310	− 47	−270	541
	D	6 1 48.372	1380.188	.014	1380.174	1372	59577	+1310	− 47	−278	562
						(2404)					(1.0060615)
July 8	B	9 12 54.420									
	B	9 19 14.691	380.271	.022	380.249	378	1.0059497	+1310	− 57	−270	1.0060480
[Rejected.]	B	9 30 30.691	676.000	.020	675.980	672	59226	+1310	− 57	−273	206
	B	9 52 20.428	1309.737	.013	1309.724	1302	59324	+1310	− 57	−276	301
						(2352)					(1.0060303)
July 9	D	6 14 46.203									
	A	6 22 2.823	436.620	.022	436.598	434	1.0059862	+1287	−106	−232	1.0060811
	D	6 31 48.308	525.485	.018	525.467	582	59570	+1287	−106	−238	513
	D	6 54 24.353	1356.045	.015	1356.030	1348	59570	+1287	−106	−249	502
						(2364)					(1.0060562)
July 9	D	9 16 14.154									
	D	9 22 40.466	386.312	.023	386.289	384	1.0059609	+1287	− 98	−292	1.0060506
	D	9 32 56.136	615.670	.018	615.652	612	59673	+1287	− 98	−293	569
	D	9 55 24.160	1348.024	.014	1348.010	1340	59776	+1287	− 98	−294	671
						(2336)					(1.0060639)
July 10	B	5 28 2.285									
	B	5 34 48.716	406.431	.023	406.408	404	1.0059604	+1300	−114	−216	1.0060574
	B	5 44 58.357	609.641	.018	609.623	606	59785	+1300	−114	−213	758
	B	6 8 22.704	1404.347	.014	1404.333	1336	59692	+1300	−114	−217	661
						(2346)					(1.0060571)
July 10	B	9 35 56.718									
	D	9 43 26.400	449.682	.023	449.659	447	1.0059485	+1300	−115	−226	1.0060444
	C	9 53 7.879	581.479	.019	581.460	578	59862	+1300	−115	−231	816
	C	10 15 41.910	1354.031	.014	1354.017	1346	59562	+1300	−115	−237	510
						(2371)					(1.0060572)

UNITED STATES COAST SURVEY.—PENDULUM AT HOBOKEN.

HEAVY END DOWN.

Date.	Chr.	Method.	Time of transit.	Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp.	Period, corrected.
			h. m. s.	s.								
June 11	380	D	15 33 13.345									
		A	49 3.937	950.592	.056	950.536	944½	1.0063913	− 57	−60	−363	1.0063433
		B	16 16 18.874	1634.937	.048	1634.889	1624½	3952	− 57	−60	−363	472
		B	17 8 24.798	3125.924	.031	3125.893	3106	4047	− 57	−60	−363	567
							(5675)					(1.0063518)
June 14	387	A	13 59 53.591									
		D	14 14 44.815	891.224	.051	891.178	885½	1.0064069	−288	−63	−377	1.0063341
		B	38 14.865	1410.050	.043	1410.007	1401	4289	−288	−63	−377	561
		D	15 30 14.824	3119.959	.035	3119.924	3100	4273	−288	−63	−377	545
							(5386½)					(1.0063516)
June 15	380	D	15 22 38.937									
		B	35 12.769	753.832	.044	753.788	749	1.0063923	− 68	−51	−436	1.0063368
		D	59 17.029	1444.260	.046	1444.215	1435	4214	− 68	−51	−436	659
		D	16 45 50.878	2793.849	.027	2793.822	2776	4200	− 68	−51	−436	645
							(4960)					(1.0063607)
June 16	380	B	14 28 36.999									
		B	43 4.571	867.572	.050	867.522	862	1.0064056	− 68	−32	−472	1.0063484
		B	15 10 53.272	1668.701	.049	1668.651	1658	4240	− 68	−32	−472	668
		D	59 55.059	2941.787	.029	2941.758	2923	4174	− 68	−32	−472	602
							(5443)					(1.0063604)
					Change of knife-edges.							
June 17	202	B	15 54 32.711									
		D	16 10 51.967	979.256	.055	979.200	973	1.0063720	+142	−54	−432	1.0063376
		B	16 36 40.868	1548.901	.044	1548.857	1539	4048	+142	−54	−432	704
		D	17 26 28.880	2988.012	.029	2987.982	2969	3934	+142	−54	−432	590
							(5481)					(1.0063584)
June 19	202	B	14 15 25.293									
		B	29 40.743	855.450	.050	855.399	850	1.0063525	+240	−39	−456	1.0063270
		B	55 18.561	1537.818	.047	1537.771	1528	3946	+240	−39	−456	691
		D	15 45 54.822	3036.261	.038	3036.223	3017	3717	+240	−39	−456	462
							(5395)					(1.0063497)
June 20	202	D	15 4 14.856									
		D	20 0.891	946.035	.053	945.981	940	1.0063631	+240	−59	−416	1.0063396
June 22	202	C	14 31 41.930									
		A	44 53.972	792.042	.047	791.995	787	1.0063471	+336	−46	−386	1.0063375
		B	15 12 33.042	1659.070	.050	1659.020	1648½	3814	+336	−46	−386	718
		C	16 1 24.137	2931.095	.029	2931.066	2912½	3745	+336	−46	−386	649
							(5348)					(1.0063630)
June 29	202	D	10 7 24.685									
		B	21 10.950	826.265	.048	826.217	821	1.0063547	+426	−53	−404	1.0063516
		A	46 1.924	1490.974	.046	1490.927	1481½	3636	+426	−53	−404	605
		B	11 30 27.294	2665.370	.030	2665.340	2648½	3582	+426	−53	−404	551
							(4951)					(1 0063561)

UNITED STATES GEODETIC SURVEY.—PENDULUM AT HOBOKEN, 1877.

HEAVY END UP.

Date.	Chr.	Method.	Time of transit.			Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp.	Period, corrected.
			h.	*m.*	*s.*	*s.*								
June 11	202	C	14	11	38.249									
		D		18	15.367	397.118	.020	397.097	394½	1.0065830	+ 94	−139	−306	1.0065479
		A		29	24.260	668.893	.016	668.877	664½	5872	+ 94	−139	−306	5521
		A		48	31.797	1147.537	.010	1147.526	1140	6019	+ 94	−139	−306	5668
									(2199)					(1.0065590)
June 14	387	B	16	13	38.972									
		C		19	53.944	374.972	.021	374.951	372½	1.0065820	−288	−141	−323	1.0065068
		C		30	5.987	612.033	.018	612.015	608	6038	−288	−141	−323	5286
		D		56	20.856	1574.869	.016	1574.853	1564½	6594	−288	−141	−323	5842
									(2545)					(1.0065596)
June 15	380	A	14	15	1.901									
		A		20	22.026	320.125	.017	320.108	318	1.0066299	− 68	−114	−378	1.0065739
		B		30	52.683	630.657	.018	630.639	626½	6069	− 68	−114	−371	5516
		C		53	24.044	1351.361	.013	1351.348	1342½	5909	− 68	−114	−364	5363
									(2287)					(1.0065457)
June 16	380	B	13	22	44.800									
		B		28	45.183	360.383	.019	360.374	358	1.0066304	− 68	− 73	−399	1.0065764
		C		39	27.931	642.748	.018	642.729	638½	6233	− 68	− 73	−394	5698
		D	14	1	19.039	1351.108	.012	1311.096	1302½	5998	− 68	− 73	−391	5466
									(2299)					(1.0065577)
							Change of knife-edges.							
June 17	202	B	14	47	8.665									
		B		53	0.975	352.310	.018	352.292	350	1.0065497	+142	−119	−368	1.0065152
		D	15	5	0.698	719.723	.019	719.703	715	5780	+142	−119	−368	5435
		D		25	36.797	1236.099	.011	1236.088	1228	5861	+142	−119	−368	5516
									(2293)					(1.0065435)
June 19	202	"XOXO"	16	11	16.343									
		D		17	40.855	384.512	.021	384.491	382	1.0065222	+240	− 97	−386	1.0064979
		A		29	19.952	699.097	.019	699.078	694½	5027	+240	− 97	−386	5684
		D		48	43.042	1163.090	.010	1163.079	1155½	5591	+240	− 97	−386	5348
									(2232)					(1.0065389)
June 20	202	A	14	7	40.020									
		A		17	48.012	607.992	.017	607.975	604	1.0065815	+240	−136	−345	1.0065574
		B		38	36.656	1248.644	.011	1248.633	1240½	5564	+240	−136	−345	5323
									(1844½)					
June 22	202	D	16	22	58.721									
		C		27	32.028	273.307	.012	273.295	271½	1.0066110	+336	−112	−321	1.0066013
		C		37	27.926	595.898	.015	595.883	592	5586	+336	−112	−321	5489
		B		57	35.297	1207.371	.011	1207.360	1199½	5531	+336	−112	−321	5434
									(2063)					(1.0065512)
June 29	202	A	9	6	0.137									
		B		10	58.584	298.447	.016	298.431	296½	1.0065133	+426	−121	−335	1.0065103
		B		21	44.824	646.240	.019	646.220	642	5734	+426	−121	−335	5704
		D		40	39.187	1134.363	.012	1134.351	1127	5231	+426	−121	−335	5201
									(2065½)					(1.0065343)

UNITED STATES GEODETIC SURVEY.—PENDULUM AT HOBOKEN, 1877.—SWINGS AT LOW PRESSURES.

HEAVY END DOWN.

[All temperatures in low-pressure and high-temperature experiments are to be corrected by +0°.3 C.]

Date.	Pressure.	Temperature.	Method.	Time of transit.			Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Period, corrected.
	In.	°		h.	m.	s.	s.						
Sept. 25	30.25	67.6	A	10	48	26.194							
			A	11	7	45.625	1159.431	.044	1159.387	1152	1.0064123	+ 13	1.0064136
			A	11	27	25.156	1179.531	.022	1179.509	1172	4258	+ 13	271
			A	11	57	54.835	1829.679	.014	1829.665	1818	4164	+ 13	177
										(4142)			(1.0064173)
Sept. 26	15.19	66.1	A	10	48	22.909							
			A	11	44	26.903	963.994	.042	963.952	958	1.0062129	+ 13	1.0062142
			A	11	41	32.780	2225.877	.053	2225.824	2212	2495	+ 13	508
			A	12	23	24.403	2511.623	.019	2511.604	2496	2516	+ 13	529
										(5666)			(1.0062457)
Sept. 27	30.25	68.5	A	8	50	47.365							
			A	9	1	15.420	628.055	.032	628.023	624	1.0064471	+ 13	1.0064484
			A	9	19	34.448	1099.028	.030	1098.998	1092	4084	+ 13	097
			A	9	58	14.881	2320.433	.026	2260.407	2246	4145	+ 13	158
										(3962)			(1.0064194)
Sept. 29	0.50	68.3	D	10	7	12.887							
			B	10	38	21.285	1868.398	.146	1868.252	1857	1.0060592	+128	1.0060720
			A	11	8	15.753	1794.468	.127	1794.341	1783½	0785	+128	0913
			B	11	37	59.106	1783.353	.112	1783.241	1772½	0598	+128	0726
			B	12	5	17.109	1638.003	.098	1637.905	1628	0842	+128	0970
			D	12	35	59.323	1842.214	.091	1842.123	1831	0748	+128	0876
			D	13	7	48.930	1909.607	.085	1909.522	1898	0705	+128	0833
			B	13	42	28.560	2079.630	.082	2079.548	2067	0706	+128	0834
			D	14	12	50.654	1822.094	.061	1822.033	1811	0922	+128	1050
			D	14	57	16.812	2666.158	.076	2666.082	2650	0687	+128	0815
			D	15	24	6.555	1609.745	.040	1609.705	1600	0656	+128	0784
			B	15	55	2.794	1856.237	.042	1856.195	1845	0677	+128	0805
			D	16	25	57.012	1854.218	.037	1854.181	1843	0677	+128	0805
			D	17	9	32.831	2615.819	.042	2615.777	2600	0681	+128	0809
			B	17	29	4.907	1172.076	.017	1172.059	1165	0592	+128	0720
			D	18	26	24.687	3439.780	.044	3439.736	3419	0649	+128	0777
			B	18	57	57.142	1892.455	.020	1892.435	1881	0792	+128	0920
			A	19	34	33.931	2196.789	.020	2196.769	2183½	0767	+128	0895
										(33834½)			(1.0060879)
Oct. 1	4.99	68.3	A	8	18	49.961							
			D	8	49	38.866	1848.905	.121	1848.784	1837½	1.0061410	+ 9	1.0061419
			B	10	19	42.950	5404.084	.166	5403.918	5371	1288	+ 9	297
			B	10	51	26.588	1903.638	.028	1903.610	1892	1364	+ 9	373
			D	11	23	1.196	1894.611	.021	1894.590	1883	1535	+ 9	544
			D	12	11	51.086	2929.890	.012	2929.878	2912	1394	+ 9	403
			B	12	31	21.201	1170.115	.009	1170.106	1163	1101	+ 9	110 rej.
										(13895½)			(1.0061379)
Oct. 1	1.50	68.0	B	12	48	29.189							
			B	13	24	56.944	2247.755	.161	2247.594	2234	1.0060850	+ 9	1.0060859
			B	13	53	7.292	1680.348	.100	1680.248	1670	1365	+ 9	1374
			D	14	28	10.769	2103.477	.096	2043.381	2050	0760	+ 9	0769
			D	15	1	39.367	2068.598	.074	2068.524	2056	0914	+ 9	0923
			D	15	33	22.956	1903.589	.055	1903.534	1892	0962	+ 9	0971
			D	16	1	31.528	1748.572	.040	1748.532	1738	0596	+ 9	0605
			B	16	41	46.912	2355.384	.045	2355.339	2341	1252	+ 9	1261
			D	17	6	24.907	1477.995	.020	1477.975	1469	1095	+ 9	1104
			B	18	16	19.357	4194.450	.046	4194.404	4169	0935	+ 9	0944
			A	18	41	44.122	1524.765	.012	1524.753	1515½	0990	+ 9	0999
										(21115½)			(1.0060999)

PENDULUM AT HOBOKEN, 1877.—SWINGS AT LOW PRESSURES—Continued.

HEAVY END DOWN—Continued.

Date.		Pressure.	Temperature.	Method.	Time of transit.			Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Period, corrected.
		In.	°		h.	m.	s.	s.						
Oct.	3	0.25	68.5	D	9	7	46.910							
				D	9	37	20.754	1773.844	.148	1773.696	1763	1.0060669	+ 9	1.0060678
				C	10	14	43.954	2243.200	.168	2243.032	2229½	0695	+ 9	704
				D	10	39	46.646	1502.692	.104	1502.588	1493½	0850	+ 9	859
				B	11	7	16.707	1650.061	.107	1649.954	1640	0695	+ 9	704
				D	11	37	36.784	1820.077	.118	1819.959	1809	0580	+ 9	589
				D	12	6	5.210	1708.426	.098	1708.328	1698	0825	+ 9	834
				B	12	41	6.999	2101.789	.105	2101.684	2089	0718	+ 9	727
				B	13	13	34.839	1947.840	.089	1947.751	1936	0697	+ 9	706
				D	13	38	10.828	1475.989	.066	1475.923	1467	0825	+ 9	834
				B	14	8	4.704	1793.878	.071	1793.808	1783	0617	+ 9	626
				B	14	36	45.175	1720.471	.065	1720.406	1710	0854	+ 9	863
				D	15	11	42.930	2097.755	.069	2097.686	2085	0844	+ 9	853
				D	15	39	47.164	1084.234	.052	1684.182	1674	0824	+ 9	833
				B	16	3	44.881	1437.717	.041	1437.676	1429	0714	+ 9	723
				D	16	33	16.614	1771.733	.048	1771.685	1761	0676	+ 9	685
				D	17	6	8.567	1971.953	.047	1971.906	1960	0745	+ 9	754
				D	17	34	10.790	1682.223	.037	1682.190	1672	0913	+ 9	922
				B	18	10	26.929	2176.139	.044	2176.095	2163	0542	+ 9	551
				B	18	49	43.208	2356.279	.042	2356.237	2342	0790	+ 9	799
											(34704)			(1.0060746)
Oct.	5	14.98	64.4	D	9	0	1.140							
				B	9	17	52.833	1071.693	.063	1071.630	1065	1.0062253	+129	1.0062382
				B	9	54	48.623	2215.790	.068	2215.722	2202	2316	+129	445
				D	11	2	54.925	4086.302	.038	4086.264	4061	2211	+129	340
											(7328)			(1.0062378)
Oct.	5	14.98	64.3	A	11	13	7.823							
				D	11	32	58.754	1190.931	.067	1190.864	1133½	1.0062223	+129	1.0062352
				D	12	7	46.697	2087.943	.061	2087.882	2075	2082	+129	211
				B	13	18	12.864	4226.167	.038	4226.129	4200	2212	+129	341
											(7458½)			(1.0062306)
Oct.	5	30.16	64.7	A	13	30	39.866							
				B	13	42	22.876	703.010	.037	702.973	698½	1.0064037	+129	1.0064166
				B	14	2	26.846	1203.670	.034	1203.636	1196	3846	+129	3975
				A	14	49?	17.896	2811.350	.027	2811.324	2793½	3805	+129	3934
											(4688)			(1.0063979)
Oct.	5	30.16	64.5	D	14	58	45.016							
				B	15	10	56.685	731.669	.039	731.630	727	1.0063686	+129	1.0063815
				D	15	30	7.029	1150.344	.032	1150.312	1143	3972	+129	4101
				B	15	15	15.206	2708.177	.027	2708.150	2691	3731	+129	3860
											(4561)	....	....	(1.0063913)

PENDULUM AT HOBOKEN, 1877.—SWINGS AT LOW PRESSURES—Continued.

HEAVY END UP.

Date.	Pressure.	Temperature.	Method.	Time of transit.			Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Period, corrected.
1877.	*In.*	°		*h.*	*m.*	*s.*	*s.*						
Nov. 30	0.39	....	A	13	50	25.592							
		51.6	A	14	45	4.562	3278.970	.240	3278.730	3260	1.0057454	+367	1.0057821
		51.3	A	15	[illegible]	16.464	2411.902	.111	2411.791	2398	57510	+367	877
		51.0	A	16	17	6.318	3109.854	.095	3109.759	3092	57435	+367	802
		50.6	A	17	15	16.274	3189.956	.064	3489.892	3470	57326	+367	693
		50.5	A	17	38	42.309	1406.035	.017	1406.018	1398	57353	+367	720
										(13618)			(1.0057784)
Dec. 4	7.47	48.0	D	11	10	8.716							
			B	11	18	38.728	510.012	.032	509.980	507	1.0058777	+369	1.0059146
			D	12	29	8.732	4230.004	.081	4229.923	4205	59270	+369	9639
			B	12	31	40.604	151.872	.000	151.872	151	57748	+369	8117
										(4863)			(1.0059540)
Dec. 8	0.35	48.7	B	10	46	34.876							
			B	11	30	42.130	2647.254	.195	2647.069	2632	1.0057253	+353	1.0057606
			B	12	30	42.790	3600.660	.156	3600.504	3580	57274	+353	627
			B	13	34	50.774	3847.984	.091	3847.893	3826	57221	+353	574
			B	14	31	44.256	3413.482	.044	3413.438	3394	57272	+353	625
			B	15	27	37.353	3353.097	.026	3353.071	3334	57202	+353	555
										(16766)			(1.0057597)
Dec. 8	0.42	48.8	D	15	33	29.256							
			B	16	33	2.802	3573.546	.194	3573.352	3553	1.0057281	+353	1.0057634
			B	17	43	40.999	4238.197	.122	4238.075	4214	57131	+353	484
			B	19	10	34.758	5213.759	.070	5213.689	5184	57270	+353	623
			B	19	45	48.809	2114.051	.015	2114.036	2102	57260	+353	613
			D	20	34	54.576	2945.767	.014	2945.753	2929	57197	+353	550
										(17982)			(1.0057579)
Dec. 10	0.67	49.4	B	12	5	30.825							
			D	12	44	21.293	2330.468	.170	2330.298	2317	1.0057389	+389	1.0057778
			D	13	27	16.098	2574.805	.117	2574.688	2560	57375	+389	764
			D	14	51	33.072	5056.974	.112	5056.862	5028	57403	+389	792
			B	15	28	30.747	2217.675	.023	2217.652	2205	57379	+389	768
										(12110)			(1.0057778)
Dec. 10	0.72	48.8	B	15	31	29.314							
			B	16	34	47.093	3797.779	.166	3797.613	3776	1.0057238	+389	1.0057627
			B	17	43	24.675	4117.582	.082	4117.500	4094	57401	+389	790
			B	19	1	41.431	4696.756	.040	4696.716	4670	57208	+389	597
										(12540)			(1.0057669)
Dec. 12	29.87	50.8	D	13	3	14.877							
			D	13	38	42.675	2127.798	.024	2127.774	2114	1.0065156	+283	1.0065439
Dec. 12	29.95	52.1	B	15	39	35.317							
			B	17	00	12.625	4837.308	.039	4837.269	4806	1.0065062	+283	1.0065349
Dec. 12	29.03	51.1	B	17	24	27.023							
			B	18	15	46.956	3079.933	.031	3079.902	3060	1.0065039	+283	1.0065322
Dec. 14	30.24	48.6	B	18	15	36.941							
			B	18	52	1.055	2184.114	.026	2184.088	2170	1.0064922	+329	1.0065247
Dec. 16	27.20	50.2	D	7	24	47.072							
			D	8	1	47.321	2220.249	.038	2220.211	2206	1.0064419	+356	1.0064775
Dec. 16	27.20	50.2	D	8	10	58.858							
			B	8	44	6.577	1987.719	036	1987.683	1975	1.0064218	+356	1.0064574

PENDULUM AT HOBOKEN, 1877.—SWINGS AT LOW PRESSURES—Continued.

HEAVY END UP—Continued.

Date.	Pressure.	Temperature.	Method.	Time of transit.	Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Period, corrected.
1877.	*In.*	°		*h. m. s.*	*s.*						
Dec. 16	29.15	50.2	B	9 06 56.915							
			D	9 40 39.025	2022.110	.033	2022.077	2009	1.0065092	+356	1.0065448
Dec. 16	29.05	50.5	D	9 51 20.849							
			D	10 22 28.955	1868.106	.030	1868.076	1856	1.0065065	+356	1.0065421
Dec. 16	22.45	50.9	B	11 21 36.680							
			B	11 59 43.101	2286.421	.036	2286.385	2272	1.0063402	+356	1.0063670
Dec. 17	15.02	50.4	B	12 22 32.587							
			D	13 20 16.792	3464.205	.063	3464.142	3443	1.0061406	+376	1.0061782
Dec. 17	7.45	50.5	D	16 1 52.821							
			D	17 26 51.046	5098.225	.093	5098.132	5068	1.0059455	+376	1.0059831
Dec. 19	0.64	50.1	D	12 38 2.610							
			B	13 39 30.870	3688.260	.216	3688.044	3667	1.0057388	+335	1.0057723
			B	14 42 54.668	3803.898	.104	3803.694	3782	– 57361	+335	696
			D	15 44 36.884	3702.216	.048	3702.168	3681	57506	+335	841
								(11130)			(1.0057752)
Dec. 19	1.00	50.0	B	15 51 9.164							
			B	16 53 14.595	3725.431	.162	3725.269	3704	1.0057421	+335	1.0057756
			D	17 55 43.088	3748.493	.072	3748.421	3727	57475	+335	810
			B	18 56 0.814	3617.726	.032	3617.694	3597	57531	+335	866
								(11028)			(1.0057813)
Dec. 22	0.38	49.7	B	11 44 24.745							
			B	12 7 34.722	1389.977	.088	1389.889	1382	1.0057084	+406	1.0057490
			B	14 3 40.572	6965.847	.248	6965.599	6926	57174	+406	580
			B	15 2 54.889	3554.320	.053	3554.267	3534	57349	+406	755
			D	17 7 56.626	7501.737	.051	7501.686	7459	57227	+406	633
			B	17 34 40.764	1604.136	.005	1604.131	1595	57249	+406	654
								(20896)			(1.0057628)
Dec. 22	0.81	49.5	D D	18 30 28.843							
			D D	19 2 12.749	1903.906	.041	1903.865	1893	1.0057390	+406	1.0057796
			D B	19 46 50.573	2677.823	.036	2677.787	2662½	57416	+406	822
								(4555½)			(1.0057813)
Dec. 23	0.46	49.0	D B	4 22 53.989							
			D	4 48 42.354	1548.365	.047	1548.318	1539½	1.0057278	+406	1.0057684
			D D	5 19 8.774	1826.420	.043	1826.377	1816	57142	+406	548
								(3355½)			(1.0057611)
Dec. 23	0.82	49.0	D	6 40 36.960							
			B	7 13 43.405	1986.445	.135	1986.310	1975	1.0057266	+406	1.0057672
			D	8 19 39.117	3955.712	.145	3955.567	3933	57379	+406	785
			D	9 47 1.082	5241.965	.076	5241.889	5212	57347	+406	753
			D	14 16 35.199	1774.116	.012	1774.104	1764	57279	+406	685
								(12884)			(1.0057741)
Dec. 23	30.55	49.6	D	10 37 55.017							
			B	11 10 22.653	1947.636	.037	1947.599	1935	1.0065111	+406	1.0065517
Dec 23	30.55	48.9	D	11 14 36.834							
			B	11 48 2.889	2006.055	.043	2006.012	1993	1.0065289	+406	1.0065695

UNITED STATES GEODETIC SURVEY.—PENDULUM AT HOBOKEN.—SWINGS AT HIGH TEMPERATURE.

HEAVY END UP.

Date.	Pressure.	Temp. F.	Method.	Time of transit.			Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp. to 35° C.	Period, corrected.
1878.	In.	°		h.	m.	s.	s.								
Apr. 24	1.24	....	D	11	52	17.358									
		92.5	B	12	5	25.088	787.730	.042	787.688	783	1.0059872	+ 8	......	+100	1.0059980
		92.6	D	12	18	20.755	775.667	.035	775.632	771	60078	+ 8	......	+ 91	60177
		92.0	D	12	30	31.137	730.382	.028	730.354	726	59972	+ 8	......	+128	60108
										(2280)					(1.0060088)
Apr. 26	2.25	....	B	11	3	13.343									
		99.3	B	11	24	0.896	1247.553	.038	1247.515	1240	1.0060605	+ 8	......	−244	1.0060369
		100.8	D	11	53	54.768	1793.872	.034	1793.838	1783	60785	+ 8	......	−316	60477
		101.5	B	12	24	6.767	1811.999	.022	1811.977	1801	60949	+ 8	......	−352	60605
										(4824)					(1.0060497)
Apr. 24	29.888	....	B	10	8	11.240									
		89.9	D	10	19	46.835	695.595	.030	695.565	691	1.0066064	+ 8	−59	+178	1.0066191
		90.5	B	12	32	16.830	749.995	.012	749.983	745	66886	+ 8	−59	+157	66992
		91.0	D	10	50	8.937	1072.107	.006	1072.101	1065	66696	+ 8	−59	+135	66780
										(2501)					(1.0066670)
Apr. 26	29.886	....	D	8	49	46.929									
		96.5	B	8	57	4.888	437.959	.020	437.939	435	1.0067563	+ 8	−60	− 78	1.0067459
		97.0	D	9	5	31.263	506.375	.011	506.314	503	66885	+ 8	−60	−100	66733
		97.8	D	9	25	41.330	1210.067	.010	1210.057	1202	67030	+ 8	−60	−135	66843
										(2140)					(1.0066936)
Apr. 26	29.890	....	D	9	28	27.344									
		97.8	D	9	33	9.253	281.909	.018	281.891	280	1.0067536	+ 8	−60	−135	1.0067349
		97.9	D	9	42	12.885	543.632	.016	543.616	540	66963	+ 8	−60	−135	66776
		98.6	B	10	5	51.382	1418.497	.015	1418.482	1409	67296	+ 8	−60	−164	67080
										(2229)					(1.0067039)
Apr. 30	30.000	....	D	9	4	59.956									
		102.8	B	9	12	1.115	421.859	.019	421.840	419	1.0067780	− 9	−85	−328	1.0067358
		102.8	B	9	21	49.060	587.945	.014	587.931	584	67312	− 9	−85	−328	66890
		102.7	D	9	44	53.336	1384.276	.010	1384.266	1375	67389	− 9	−85	−328	66967
										(2378)					(1.0067017)
Apr. 30	30.007	....	B	9	47	45.072									
		102.7	D	9	55	33.220	468.448	.027	468.121	465	1.0067263	− 9	−87	−328	1.0066839
		102.5	D	10	5	27.224	594.004	.016	593.988	590	67593	− 9	−87	−320	67177
		102.3	B	10	26	40.780	1273.556	.011	1273.545	1265	67549	− 9	−87	−313	67140
										(2320)					(1.0067060)
May 2	29.897	....	D	11	05	33.347									
		95.2	D	11	13	58.729	505.382	.025	505.357	502	1.0066873	−45	−61	− 28	1.0066739
		95.4	D	11	28	44.682	885.953	.016	885.937	880	67466	−45	−61	− 36	67324
		95.6	B	11	46	26.759	1062.077	.006	1062.071	1055	67024	−45	−61	− 43	66875
										(2437)					(1.0067007)
May 2	29.892	....	D	11	49	35.047									
		96.0	D	11	55	31.417	356.370	.019	356.351	354	1.0066412	−45	−60	− 64	1.0066243
		96.3	D	12	03	26.619	475.202	.013	475.189	472	67563	−45	−60	− 71	67387
		96.7	D	12	22	53.429	1166.810	.012	1166.798	1159	67282	−45	−60	− 85	67092
										(1985)					(1.0067011)
May 10	29.899	....	D	10	11	18.725									
		91.1	D	10	17	37.254	378.529	.017	378.512	376	1.0066809	+28	−62	+135	1.0066910
		91.5	D	10	27	11.098	573.844	.013	573.831	570	67211	+28	−62	+114	67291
		92.3	D	10	51	59.023	1487.925	.011	1487.914	1478	67077	+28	−62	+ 85	67128
										(2424)					(1.0067132)
May 10	29.892	....	B	10	55	38.701									
		92.5	D	11	8	12.735	454.034	.022	454.012	451	1.0066785	+28	−60	+ 78	1.0066831
		92.5	D	11	13	22.820	610.085	.014	610.071	606	67178	+28	−60	+ 78	67224
		92.8	D	11	33	30.913	1208.093	.010	1208.083	1200	67358	+28	−60	+ 64	67390
										(2257)					(1.0067734)
May 11	29.968	....	B	9	42	29.411									
		93.7	D	9	48	56.995	387.584	.016	387.568	385	1.0066701	+28	−78	+ 28	1.0066679
		94.0	D	9	58	28.845	631.850	.012	571.838	568	67570	+28	−78	+ 21	67541
		94.4	B	10	21	35.105	1386.260	.010	1386.250	1377	67175	+28	−78	0	67125
										(2330)					(1.0067153)
		....	D	10	25	16.895									
	29.980	94.4	B	10	32	48.935	452.040	.024	452.016	449	1.0067171	+28	−81	0	1.0067118
		94.3	B	10	42	40.894	591.959	.012	591.947	588	67126	+28	−81	+ 7	67080
		94.0	D	11	10	49.181	1688.287	.012	1688.575	1677	67233	+28	−81	+ 21	67201
										(2714)					(1.0067161)

PENDULUM AT HOBOKEN.—SWINGS AT HIGH TEMPERATURE—Continued.

HEAVY END DOWN.

Date.	Pressure.	Temp. F.	Method.	Time of transit.			Intervals.	Cor. for arc.	Corr. time.	Number oscillations.	Time, one oscillation.	Rate.	Cor. for pressure.	Cor. for temp. to 35° C.	Period, corrected.
1878.	*In.*	°		*h.*	*m.*	*s.*	*s.*								
May 4	29.794	....	D	9	19	15.340									
		96.0	B	9	31	37.201	741.861	.041	741.820	737	1.0065400	−45	−16	− 75	1.0065264
		96.8	D	9	54	29.156	1371.955	.039	1371.916	1363	65414	−45	−16	−108	65245
		97.3	D	10	59	34.625	3905.469	.031	3905.438	3880	65563	−45	−16	−133	65369
										(5980)					(1.0065327)
May 5	29.868	....	B	9	13	26.830									
		94.0	D	9	26	12.843	766.013	.038	765.975	761	1.0065375	−45	−24	+ 25	1.0065329
		94.2	B	9	49	22.897	1390.054	.036	1390.018	1381	65301	−45	−24	+ 8	65240
		94.8	D	10	54	11.255	3888.358	.028	3888.330	3863	65571	−45	−24	− 17	65485
										(6005)					(1.0065409)
May 6	30.027	....	D	11	05	53.067									
		95.1	D	11	15	40.900	587.833	.026	587.807	584	1.0065188	+54	−40	− 33	1.0065169
		95.1	B	11	33	32.896	1071.996	.028	1071.968	1065	65427	+54	−40	− 33	65408
		95.1	B	12	30	31.132	3418.236	.030	3418.206	3396	65389	+54	−40	− 33	65370
										(5045)					(1.0065356)
May 8	29.843	....	B	9	57	19.379									
		96.5	D	10	9	35.213	735.834	.042	735.792	731	1.0065554	−59	−21	− 91	1.0065383
		96.1	D	10	30	23.375	1248.162	.036	1248.126	1240	65533	−59	−21	− 75	65378
		94.0	B	11	23	35.137	3191.762	.034	3191.728	3171	65367	−59	−21	+ 25	65312
										(5142)					(1.0065338)

NOTE.—For addendum to this appendix see end of volume.

APPENDIX No. 16.

[Reprinted from the United States Coast Survey Report for 1871.]

COMPARISON OF THE METHODS OF DETERMINING HEIGHTS BY MEANS OF LEVELING, VERTICAL ANGLES AND BAROMETRIC MEASURES, FROM OBSERVATIONS AT BODEGA HEAD AND ROSS MOUNTAIN, CAL., BY GEORGE DAVIDSON AND CHARLES A. SCHOTT, ASSISTANTS, UNITED STATES COAST SURVEY.

In the spring of 1860, Assistant George Davidson organized a system of observations of heights with a view of determining the refraction of the atmosphere in the climate of California, and to give data for relative values of heights determined from leveling operations, from measures of zenith-distances, and from readings of the atmospheric pressure. The stations selected were Bodega Head, on the sea-coast, about fifty statute-miles northwesterly of San Francisco, and Ross Mountain, about fourteen miles to the northward of Bodega Head. The "head" is about 240 feet and the "mountain" about 2210 feet above the level of the ocean. Starting from Bodega Head, the line passes for about one-third of its length close to the coast-line, and at two-thirds it crosses the deep valley of the Russian River. Local currents of the atmosphere, due to this valley, may possibly cause disturbances in the normal refraction.

The two stations were occupied in March, 1860, and between the 20th and 27th hourly observations (from 7 a. m. to 5 p. m.) were made of reciprocal and simultaneous zenith-distances, and of the pressure, temperature, and moisture of the atmosphere.

The height of Bodega Head was determined by leveling in August, 1860, but it was not till 1872 that an opportunity offered for carrying the levels up to Ross Mountain. The results of this paper will be given under the three divisions of the subject stated in the title.

1.—THE RESULTS OF THE LEVELING OPERATIONS.

These operations being well understood, and presenting nothing new or of special interest, the following brief statement will suffice:

The elevation of Bodega Head was determined by spirit-level by Assistant George Davidson, August 20, 1860. The staff could be read by means of a vernier to 0.001 of a foot. He found—

Bodega Head mark above bench-mark near tidal station......	234.6 feet.
Reduction to ground, or top of copper bolt	− 0.1
Reduction to half-tide level of ocean	+ 6.6
Hence Bodega Head, ground, above ocean.....................	241.1 feet = $73^{m}.49$

By direction of Assistant Davidson, the elevation of Ross Mountain was obtained by spirit-level in January, February, and March, 1872, by Mr. S. R. Throckmorton, jr., aid, United States Coast Survey, assisted by Mr. H. J. Willey. The levelings commenced at Bodega Head, and received a rough check by striking high-water mark at Salmon Creek; from here the line of level crosses a ridge of about 250 feet, and descends again at the Russian River to tide-water level; the ascent of Ross Mountain was retarded by wet and windy weather, and in returning the work had to be abandoned after descending about 1,350 feet, on account of the wet and spongy ground. The check-levels during the descent were satisfactory. The leveling-instrument, by Stackpole & Bro., of New York, was borrowed from General Alexander, United States Engineers. The rod was compared with the standard steel-yard, at 62° Fahrenheit, and the extreme length and intermediate graduation were found to agree with the standard.

The resulting difference of level is as follows:

	Feet.
Ross mountain, stone mark above ground, Bodega Head	1963.55
Reduction of mark to ground at Ross Mountain	+ 0.85
Ross Mountain, ground, above Bodega Head	1964.40
And by preceding result, Bodega Head, ground, above half-tide level of ocean	241.10
Hence, Ross Mountain, ground, above half tide of ocean	2205.50 feet,

or 672.23 meters, and the difference of height of the ground at each station 598.74 meters, with an estimated probable error of $\pm$ 0^m.06.

2.—RESULTS OF HOURLY OBSERVATIONS OF RECIPROCAL AND SIMULTANEOUS ZENITH-DISTANCES FOR DIFFERENCE OF HEIGHT OF THE TWO STATIONS.

The observations at Bodega Head, between March 20 and March 27, 1860, were made by E. H. Fauntleroy, aid, United States Coast Survey. He used the 10-inch vertical circle No. 80; it is graduated to 5′, and reads by 4 verniers to 3″ each. Its optical power was rather weak for the work required. One division of the level equals 5″.53, as determined by Assistant Davidson in 1859. The axis of the vertical circle was 62.5 inches (1.587 meters) above ground, and the elevation of the heliotrope shown to Ross Mountain was the same. The zenith distances of the Ross Mountain heliotrope were measured on five days at every full hour (excepting one on the first day) between 7 a. m. and 5 p. m. inclusive. Each measure consists of six repetitions of the double zenith-distance, and was corrected for defect of verticality of axis as indicated by the level. Immediately before and after each measure, the barometer, with attached thermometer, and the dry and wet bulb thermometers, were read, and the state of the weather noted generally, including direction and velocity of wind. The cistern of the mercurial barometer, Green No. 1343, was 0.336 meter above ground. Its index-correction, when compared with Green's mercurial barometer No. 1347, which was stated to be correct, was —0.010 inch, which correction was applied to the tabular results, as well as the graduation-corrections of the thermometers No. 16, used as dry and wet bulb, and of No. 3, used as dry bulb, after the accidental breakage of wet bulb No. 16. These corrections are given further on.

The observations at Ross Mountain, between March 20 and March 27, 1860, were made by Assistant George Davidson. He used the 10-inch Gambey vertical circle No. 28; it is graduated to 5′, and reads by 4 verniers to 3″ each. Its optical power was considered weak. One division of the level equals 6″.29, as determined by Assistant Davidson. The axis of the vertical circle was 61 inches (1.549 meter) above the ground; the heliotrope shown to Bodega Head was on a level with the vertical circle. Double zenith-distances of the Bodega Head heliotrope were measured hourly, between 7 a. m. and 5 p. m. inclusive, on five days, and at four morning-hours on the 6th day, when the observations had to be discontinued on account of wet and stormy weather. The measurement of the six repetitions of the double zenith-distance was commenced exactly at the full hour, and the average time occupied in making them was about five minutes. The level was read twice before and twice after reversal of the circle, and the results were corrected for defect in verticality of axis. The barometer and attached thermometer and the dry and wet bulb thermometers were observed as at Bodega Head; the state of the weather was carefully noted every hour. The cistern of mercurial barometer, Green No. 1347, which was borrowed from Lieut. R. S. Williamson, United States Topographical Engineers, was 0.378 meter above ground. The instrument is of the Smithsonian pattern. The thermometers were No. 8, dry bulb, No. 13, wet bulb, and the comparisons by McAllister & Bros. with a standard, and again by Assistant Davidson, gave the following index-corrections to the thermometers used at the two stations:

	°
To No. 8	0.0
To No. 13	+0.6
To No. 16, dry	+0.9
To No. 16, wet	+1.2
To No. 3	+1.1

All the thermometers have Fahrenheit's scale.

TABLE 1.—*Resulting zenith-distances, measured at Bodega Head, of the heliotrope at Ross Mountain, March,* 1860.

88° 33′+

Hour of day.	20th.	21st.	24th.	25th.	26th.	27th.	Resulting mean from five days.
	″	″	″	″	″	″	″
7 a. m.........	(*)	7.8	22.9	8.0	6.5	....	12.1
8 a. m.........	28.4	14.9	20.4	6.6	16.2	31.5	17.3
9 a. m.........	†[55.3]	29.5	38.1	[25.6]	18.9	33.3	29.4
10 a. m.........	†[11.9]	31.7	[45.2]	23.9	17.7	39.6	[30.4]
11 a. m.........	23.3	33.8	31.7	19.1	[20.3]	....	25.6
Noon	24.9	[37.7]	35.4	15.8	12.7	....	25.3
1 p. m.........	30.9	25.3	28.6	11.5	15.9	....	22.4
2 p. m.........	15.3	33.2	32.4	20.9	14.9	....	23.3
3 p. m.........	22.4	25.8	27.3	18.9	14.2	....	21.7
4 p. m.........	24.6	29.6	20.0	16.5	14.9	....	21.1
5 p. m.........	25.3	24.6	11.0	— 9.2	10.5	....	12.4
Resulting daily mean	25.3	26.7	28.5	14.3	14.8	....	21.9

The last column contains the hourly means from five days of observations, rejecting the values of the 27th, as a broken day. The maximum value on each day is indicated by an inclosure in brackets.

The probable error of any one mean zenith-distance, from five days of observation, is about ± 2″.1.

TABLE 2.—*Resulting zenith-distances, measured at Ross Mountain, of the heliotrope at Bodega Head, March,* 1860.

91° 35′+

Hour of day.	20th.	21st.	24th.	25th.	26th.	27th.	Resulting mean from five days.
	″	″	″	″	″	″	° ′ ″
7 a. m.........	44.9	68.4	87.3	79.4	69.9	82.0	91 36 10.0
8 a. m.........	58.5	85.9	91.2	81.8	68.3	90.2	17.1
9 a. m.........	79.4	90.2	93.5	86.2	81.3	95.3	26.1
10 a. m.........	84.9	87.6	[98.4]	[87.5]	77.1	96.1	27.1
11 a. m.........	81.0	90.2	96.8	84.1	[87.2]	....	[27.9]
Noon	[89.7]	88.9	92.0	77.6	83.2	....	26.3
1 p. m.........	87.6	[90.6]	94.4	77.2	77.3	....	25.4
2 p. m.........	82.6	89.4	89.8	77.9	66.2	....	21.2
3 p. m.........	87.7	82.4	93.0	78.5	73.9	....	23.1
4 p. m.........	89.4	86.1	90.7	82.4	79.4	....	25.6
5 p. m.........	86.7	80.6	89.2	80.5	69.4	....	21.3
Resulting daily mean	91 36 19.3	25.5	32.4	21.2	15.7	....	22.8

The observations on the 27th are omitted from the mean. The daily maxima are indicated by brackets. It will be noticed that these *maxima* of measured *zenith-distances* all occur in the forenoon, and that they appear to connect themselves with the time of the daily *maxima* of the *atmospheric pressure* (for which see tables further on). The average hour is near 10 a. m. This may possibly be quite local, and may be connected with the setting in of the sea-breeze about that time—a phenomenon which renders the daily fluctuation of temperature at San Francisco so different from the ordinary occurrence. The Bodega Head station seems to be slightly more exposed to this influence, as might be conjectured from its position close to the sea-coast.

* To complete the table, the value 15″.5 was here interpolated; it was found by comparing the observed zenith-distance at 7 a. m. on each day with the *mean* of the 10 observed zenith-distances of the day respectively. This difference is 10″.7, which subtracted from 26″.2, or the mean of the 10 observations on the 20th, gives 15″.5.

† Measures unreliable owing to high wind; the mean, or 33″.6, will hereafter be substituted in the place of these measures.

The probable error of any one mean zenith-distance from five days of observation is about ± 1″.9.

The heliotrope and instrument being $0^m.038$ higher above ground at Bodega Head than at Ross Mountain, the angle 0″.3 subtended by this difference will be *subtractive* to the resulting tabular zenith-distances at Bodega Head and *additive* to those at Ross Mountain, in order that the computed differences of altitude may at once refer to the ground at each station.

TABLE 3.—*Resulting atmospheric pressures observed at Bodega Head, the height of the mercurial column being corrected for index-error and its temperature reduced to that of freezing water.*

MARCH, 1860.

Hour of day.	20th.	21st.	24th.	25th.	26th.	27th.	Resulting mean from five days.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
7 a. m	(*)	29.715	30.038	29.920	29.817	....	29.833
8 a. m	29.689	.715	.038	[.930]	.827	29.765	.840
9 a. m	.731	.734	.042	.922	[.832]	.779	.852
10 a. m	[.749]	[.739]	[.049]	.923	[.832]	.780	[.858]
11 a. m	[.749]	.732	.048	.925	.825	....	.856
Noon	.744	.722	.040	.913	.809	....	.846
1 p. m	.739	.713	.018	.897	.791	....	.832
2 p. m	.741	.702	30.000	.878	.774	....	.819
3 p. m	.733	.679	29.987	.871	.761	....	.806
4 p. m	.733	.668	.965	.860	.747	....	.795
5 p. m	.730	.659	.959	.837	.732	....	.783
Mean	29.728	29.707	30.017	29.898	29.795	....	29.829

* Interpolated value for this hour 29.674 inches, using the observed difference at 7 and 8 at Ross Mountain.

Inclosed values indicate the daily maxima of pressure.

The readings on the 27th are not used in the means. The surface of the mercury in the cistern, in contact with the index-point, was $0^m.336$ above ground; hence, to reduce the observed pressure to the ground, 0.001 inch is to be added.

TABLE 4.—*Resulting atmospheric pressures observed at Ross Mountain, the height of the mercurial column being referred to the temperature of freezing water.*

MARCH, 1860.

Hour of day.	20th.	21st.	24th.	25th.	26th.	27th.	Resulting mean from five days.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
7 a. m	27.618	27.617	27.930	27.844	27.737	27.676	27.749
8 a. m	.633	.624	.934	.846	.745	.691	.756
9 a. m	.647	.635	.942	.848	.754	.699	.765
10 a. m	.651	.636	.948	[.869]	[.758]	.713	[.772]
11 a. m	[.656]	[.642]	[.949]	.852	.754	....	.771
Noon	.650	.638	.947	.840	.744	....	.764
1 p. m	.645	.621	.931	.821	.732	....	.750
2 p. m	.637	.602	.919	.803	.721	....	.736
3 p. m	.630	.597	.898	.793	.701	....	.724
4 p. m	.626	.576	.884	.782	.693	....	.712
5 p. m	.622	.572	.877	.775	.678	....	.705
Mean	27.638	27.615	27.924	27.825	27.729	....	27.746

The readings on the 27th are not used in the means.

To reduce the observed pressure to what it would have been on the ground, add 0.001 inch.

The next following tables contain the observed temperatures of the air and of evaporation; all the readings were corrected for index-errors of thermometers. The readings on the 27th are omitted; maxima are indicated by brackets.

TABLE 5.—*Observed temperature of the air and of evaporation at Bodega Head, March, 1860.*

Hour.	20th.		21st.		24th.		25th.		26th.		Mean of five days.	
	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.
	°	°	°	°	°	°	°	°	°	°		°
7 a. m.	*48.0	*46.1	43.4	42.8	46.7	45.6	48.4	46.8	49.5	48.5	47.2 F.	46.0 F.
8 a. m.	49.4	46.7	50.0	46.0	48.4	47.0	52.9	49.3	50.9	49.5	50.3	47.7
9 a. m.	50.5	47.3	52.3	47.2	53.1	49.8	55.9	51.2	52.3	50.6	52.8	49.2
10 a. m.	50.8	47.9	55.4	49.7	58.5	53.2	[57.9]	53.0	53.5	51.0	55.2	51.0
11 a. m.	50.8	47.9	[57.9]	51.0	59.4	52.4	56.1	51.5	54.8	51.7	55.8	50.9
Noon	50.6	46.8	57.0	50.5	60.5	53.8	55.9	51.3	56.1	53.8	56.0	51.1
1 p. m.	[50.9]	47.3	57.5	50.7	[60.7]	54.5	55.2	51.5	56.9	54.2	[56.2]	51.6
2 p. m.	50.0	46.5	53.5	48.4	58.9	54.2	55.5	53.1	[58.4]	†56.4	55.3	51.7
3 p. m.	49.9	46.5	52.4	48.3	58.3	53.8	53.9	51.9	56.5	55.1	54.2	51.1
4 p. m.	49.1	46.0	51.6	47.7	57.9	53.7	53.0	51.5	55.9	54.3	53.5	50.6
5 p. m.	48.7	45.7	50.1	47.7	56.5	52.3	52.6	51.1	55.5	54.1	52.7	50.2
Mean	49.9	46.8	52.8	48.2	56.3	51.7	54.3	51.1	54.6	52.7	53.56	50.10

* These two values are interpolated. † This value is interpolated.

TABLE 6.—*Observed temperatures of the air and of evaporation at Ross Mountain, March, 1860.*

Hour.	20th.		21st.		24th.		25th.		26th.		Mean of five days.	
	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.
	°	°	°	°	°	°	°	°	°	°	°	°
7 a. m.	46.0	35.3	44.0	36.7	40.5	38.8	47.4	43.4	49.6	43.2	45.5 F.	39.5 F.
8 a. m.	45.0	36.6	43.6	36.6	43.1	40.2	48.7	43.6	51.6	44.7	46.4	40.3
9 a. m.	48.5	39.7	45.3	38.7	45.1	41.6	54.4	48.6	56.5	50.2	50.0	43.8
10 a. m.	49.7	42.2	47.7	41.1	48.2	43.0	55.2	47.8	57.5	49.5	51.7	44.7
11 a. m.	51.3	44.9	49.3	42.7	51.0	45.6	56.5	50.6	60.0	52.5	53.6	47.3
Noon	[52.2]	44.8	50.7	42.5	53.7	48.5	57.0	50.8	62.6	54.8	55.2	48.3
1 p. m.	52.1	43.6	[52.0]	43.3	[56.9]	50.3	57.3	50.5	[63.4]	55.6	[56.3]	48.7
2 p. m.	51.9	43.1	49.5	42.3	55.4	49.6	57.2	48.9	61.8	53.7	55.2	47.5
3 p. m.	51.0	44.2	50.7	42.9	54.2	48.0	[58.4]	52.1	59.9	52.8	54.8	48.0
4 p. m.	47.7	42.7	46.9	40.4	52.8	47.1	[58.4]	52.1	59.2	52.3	53.0	46.9
5 p. m.	43.3	40.0	45.0	38.1	50.0	45.1	54.5	48.9	57.8	47.7	5[illegible]1	44.0
Mean	49.0	41.6	47.7	40.5	50.1	45.3	55.0	48.8	58.2	50.6	51.98	45.36

Collecting our preceding mean results, we have the following data for computation:

March 20, 21, 24, 25, 26, 1860.

Hour of day.	Observed zenith distance at—						Atmospheric pressure at—		Atmospheric temperature at—		Temperature of evaporation at—	
	Bodega Head.			Ross Mountain.			Bodega Head.	Ross Mountain.	Bodega Head.	Ross Mountain	Bodega Head.	Ross Mountain
	°	′	″	°	′	″	*Inches.*	*Inches.*	°	°	°	°
7 a. m.	88	33	11.8	91	36	10.3	29.834	27.750	47.2 F.	45.5 F.	46.0 F.	39.5 F.
8 a. m.			17.0			17.4	.841	.757	50.3	46.4	47.7	40.3
9 a. m.			29.1			26.4	.853	.766	52.8	50.0	49.2	43.8
10 a. m.			30.1			27.4	.859	.773	55.2	51.7	51.0	44.7
11 a. m.			25.3			28.2	.857	.772	55.8	53.6	50.9	47.3
Noon			25.0			26.6	.847	.765	56.0	55.2	51.1	48.3
1 p. m.			22.1			25.7	.833	.751	56.2	56.3	51.6	48.7
2 p. m.			23.0			21.5	.820	.737	55.3	55.2	51.7	47.5
3 p. m.			21.4			23.4	.807	.725	54.2	54.8	51.1	48.0
4 p. m.			20.8			25.9	.796	.713	53.5	53.0	50.6	46.9
5 p. m.			12.1			21.6	.784	.706	52.7	50.1	50.2	44.0
Mean	88	33	21.6	91	36	23.1	29.830	27.747	53.56	51.98	50.10	45.36

Notes respecting state of the weather at the two stations:

MARCH 20, 1860.

Bodega Head.—At 7^h wind strong, WNW.; atmosphere hazy. At 11^h wind blowing a gale.

Ross Mountain.—At 7^h moderately clear, sky 0.3 covered with cirrus and cirro-stratus; wind moderate, NNW.; fog to seaward and in Russian River. At 8^h fog disappeared in Russian River Valley. At 10^h fog forming along the coast south of Bodega; appears to blow fresh on the water. At 11^h wind north, light, weather getting a little thick. At noon, somewhat clearer. At 1^h wind moderately strong, NNW. At 3^h atmosphere very hazy. At 5^h wind moderately strong, N.

MARCH 21, 1860.

Bodega Head.—At 7^h weather clear, wind light, E. At 11^h wind light, SE. At 2^h wind fresh, SW. At 3^h horse-tail clouds. At 5^h thick clouds overhead.

Ross Mountain.—At 7^h weather clear, calm. At 9^h wind very light, WSW., cirro-stratus to northward. At 11^h wind light, S. by W. At 1^h light wind, SSW. At 4^h sky 0.9 covered, threatening to the northwestward, wind SSW. increasing. At 5^h wind S., light. At 5^h 15^m parhelia formed, showing three-fourths of a circle, lower part not visible; two very bright prismatic images of the sun, and a faint one at vertex.

MARCH 22 AND 23, 1860.

Weather quite stormy. At 8 a. m., on the 22d, most severe squalls of wind, with rain, from the SSW. On the 23d occasional squalls; wind SSW.

MARCH 24, 1860.

Bodega Head.—At 7^h clear; wind light, SSE. At noon wind light, SW.; atmosphere clear.

Ross Mountain.—At 7^h clear, wind very light, ESE.; snow on all the mountains eastward. At 8^h wind light, E. by N. At 9^h wind light, ESE. At noon sky half covered with cumulus, wind light, S. At 1^h wind light, WSW., and S. for the rest of the day.

MARCH 25, 1860.

Bodega Head.—At 7^h weather clear; wind very light from E. At 10^h wind light, SW. At noon fresh from W. At 2^h fog forming rapidly on line to Ross Mountain. At 3^h heliotrope seen over the line of fog; scud flying over station.

Ross Mountain.—At 7^h clear, wind S., light; sky 0. At 1^h wind light, SW. At 2^h fog forming rapidly over water, and coming in. At 3^h fog just inside our line, heliotrope seen over edge of fog-cloud. At 4^h and 5^h wind light, W. and NW.; clear.

MARCH 26, 1860.

Bodega Head.—At 7^h clear, light wind, WNW.; atmosphere hazy. At 3^h wind fresh from SW.

Ross Mountain.—At 7^h clear, wind moderate, N.; atmosphere hazy to S. At 9^h wind very light, SW.; haze on line of sight. At 10^h almost calm, clear. At noon wind very light, ENE. 1^h to 3^h wind light, S. 4^h to 5^h wind very light, SSW.; clear.

MARCH 27, 1860.

Weather cloudy, sky covered with cirro-stratus and cumulo-stratus; valleys covered with fog. Wind light ESE., between 7^h and 10^h. After 10^h rain in NW., working toward SE.; wet and stormy, with heavy gales from SE. round to SW. For the six succeeding days the fall of rain was registered 9½ inches.

The direction of wind given in the above notes refers to the true meridian. These notes are extracts from the more copious record.

The geographical positions of the stations are as follows:

Bodega Head.—Geodetic latitude, 38° 18′ 18″.7; longitude, 123° 03′ 49″.2 west of Greenwich.

Ross Mountain.—Astronomical latitude, 38° 30′ 10″.0; longitude, 123° 07′ 13″.1 west of Greenwich.

Geodetic distance of stations 22482.2 meters, and azimuth of line from Bodega Head 167° 18′

35″, and reverse azimuth from Ross Mountain 347° 16′ 29″, counted from the south point around by west.

We have also the radius of curvature* to the earth's surface in latitude φ and in azimuth α

$$= \frac{a\,(1 - e^2)}{(1 - e^2 + e^2 \cos^2\varphi \cos^2\alpha)\ (1 - e^2 \sin^2\varphi)^{\frac{1}{2}}}$$

where—

$$e^2 = \frac{a^2 - b^2}{a^2}$$

and the semi-axes, according to Clarke,

$$a = 6\ 378\ 206 \text{ meters}$$
$$b = 6\ 356\ 584 \text{ meters}$$

hence—

radius of curvature to our line = 6 361 215 meters.

Reduction of observations of zenith distances.—For reducing these observations, we shall make use of Dr. Bauernfeind's investigations respecting atmospheric refraction, as presented in Nos. 1478–1480 and in Nos. 1587–1590 of the Astronomische Nachrichten (1866). These developments are preferred to others on account of their completeness and for the reason that the simple fundamental assumptions made respecting the physical constitution of the atmosphere apparently lead to results in tolerably close conformity with experience.

Terrestrial refraction between any two stations is conceived as the difference of the astronomical refractions of a ray of light passing between them, and the equation to the refracted ray is determined with consideration of the particular circumstances of atmospheric pressure and temperature, as noted at the intersecting stations.

Let—

$\alpha_0 = 0.00027895$, a mean value for constant of refraction, at

$\beta_0 = 29.6$ inches ($751^{mm}.83$) of atmospheric pressure, and

$\theta_0 = 507°.7$ Fahr., counted from the absolute zero;

$\beta =$ observed atmospheric pressure, the mercurial column being at the temperature of freezing water;

$\theta =$ observed temperature $= 459° + \tau$, where τ must be expressed in degrees of Fahrenheit's scale;

$\alpha = \frac{\theta_0\,\beta}{\theta\,\beta_0}\,\alpha_0 = \frac{[7.67983]\,\beta}{459 + \tau}$ the rectangular brackets, including a logarithm and β to be expressed in inches;†

$r_0 =$ the radius of curvature to the earth's surface in the latitude of the middle point of the arc joining the stations and in the azimuth of the line;

$m_0 =$ a second constant (for a given latitude and elevation) depending on the refraction, and $= 0.007464$ for the latitude of Königsberg; its values for various latitudes are given in the following table:

Lat.	m_0	log m_0	Lat.	m_0	log m_0	Lat.	m_0	log m_0
°			°			°		
0	0.008300	7.91907	41	0.007740	7.88875	51	0.007547	7.87782
10	8253	.91666	42	719	8756	52	528	7668
20	8135	.91040	43	697	8632	53	510	7564
30	7939	.89977	44	675	8508	54	491	7454
35	7857	.89531	45	655	8395	55	473	7351
36	7839	.89426	46	637	8292	60	388	6856
37	7818	.89310	47	619	8190	65	303	6352
38	7800	.89214	48	602	8093	70	262	6109
39	7779	.89092	49	585	7996	80	185	5646
40	7759	.88984	50	567	7892	90	161	5499

* A table giving the logarithm of the radius for various latitudes and azimuths is appended to this paper. The uncertainties in the figure of the earth make the sixth place of the logarithms unreliable.

† For the centigrade scale and millimeters of pressure—

$$\theta_0 = 282°.1 \qquad \theta = 272°.8 + \tau \text{ and } \alpha = \frac{[6.01981]\,\beta}{+}.$$

h = elevation of observing-station above the sea-level;

$y = \frac{h}{m_0 r_0}$ and $m = \frac{(1-y)^6}{1+m_0 y} \cdot \frac{a_0}{a} \cdot m_0$; also $v = \frac{5a}{m}$;

$\rho = r_0 + h$;

d = horizontal linear distance between the two stations at the sea-level, expressed in meters

$\psi = \frac{d}{r_0}$ = distance in parts of radius or $\frac{[5.3144251]d}{r_0}$ in seconds of arc;

Δh = difference of height;

ζ = observed zenith-distance; and

$$p = m \frac{(\cos^2 \zeta + 1 - v)}{\cos^2 \zeta}$$

$$\Delta h = \rho \psi \left\{ \cot \zeta + \frac{\cos^2 \zeta + 1 - v}{2 \sin^2 \zeta} \psi + \frac{2 v \cot \zeta}{3 m \sin^2 \zeta} \psi^2 + \frac{v (p-3) \cot^2 \zeta}{6 m^2 \sin^2 \zeta} \psi^3 + \ldots \right\}$$

H = elevation of observed station = $h + \Delta h$.

Applying these formulæ to the hourly observations of zenith-distances, we obtain the following resulting values for difference of height:

Hour.	Δh from observations at Bodega Head.	Δh from observations at Ross Mountain.	Mean Δh	
	m.	*m.*	*m.*	
7 a. m......	+600.365	−596.374	598.370	
8 a. m......	599.881	597.126	.503	
9 a. m......	598.623	598.014	.318	
10 a. m......	598.578	598.081	.329	
11 a. m......	599.119	598.115	.617	
Noon	599.161	597.896	.528	
1 p. m......	599.489	597.762	.625	
2 p. m	599.374	597.325	.350	
3 p. m......	599.525	597.538	.531	
4 p. m......	599.576	597.851	.714	
5 p. m......	600.508	597.458	.983	
				m.
Means	+599.473	−597.595	598.533	±0.041

These results are shown graphically on the accompanying diagram, which also gives a representation of the observed pressure and temperature of the air at the two stations.

It will be seen that the accord with the result from the leveling-operation is quite close, the difference only amounting to $0^m.21$; but if we compare the results derived from the two stations separately, we have a difference of $1^m.88$, which reduces to $1^m.36$ if we confine ourselves to the hours between 9 and 4, both inclusive. This would indicate that the adopted constant of refraction requires a small change to suit the particular circumstances. The observations at Bodega Head give too much difference of height, and the observations at Ross Mountain too little difference of height. In either case, the constant employed makes the ray of light pass above the true height, which indicates that the adopted radii of curvature of the ray are too great, or that the assumed refraction is too small. If we increase a_0 or v by one-ninth of its value, we find results which, in their mean values, are almost identical, viz, from observations at Bodega Head, $598^m.69$; from Ross Mountain, $598^m.35$; mean, $598^m.52$; and after omitting results for the hours 7 and 8 a. m. and 5 p. m., when the atmosphere is too much agitated by currents, from observations at Bodega Head, $598^m.40$; from Ross Mountain, $598^m.58$; mean, $598^m.49$. The character of the curves, as given

on the diagram, remains the same for any small change in a_0, but the investigation of the angles of refraction makes the desirability of any such change a matter of doubt.

Let—

Z and Z' = the true zenith-distances at the lower and upper stations, refraction having no existence;

H and H' = the known (by level) elevations of the two stations; also $H_0 = \frac{1}{2}(H + H')$; and $d\ \psi\ r_0$ = the same quantities as before.

Then the values of Z and Z' can be found from the expressions—

$$\tfrac{1}{2}(Z' + Z) = 90^\circ + \tfrac{1}{2}\psi$$

$$\tfrac{1}{2}(Z' - Z) = \tan^{-1}\left\{\frac{H' - H}{d}\left(1 - \frac{H_0}{r_0} - \frac{d^2}{12 r_0^2}\right)\right\}$$

And the angles of refraction become—

$$\Delta\zeta = \zeta - Z;\ \text{also the total refraction } r = \Delta\zeta + \Delta\zeta' = \psi + 180^\circ - (\zeta + \zeta')$$
$$\Delta\zeta' = \zeta' - Z'$$

In our case $Z = 88^\circ\ 34'\ 32''.9$ and $Z' = 91^\circ\ 37'\ 36''.1$.

The following table contains the resulting refraction for the hourly measures:

Hour.	$180^\circ - (\zeta+\zeta')$	r	Observed angle of refraction at Bodega Head.	Observed angle of refraction at Ross Mountain.
	′ ″	′ ″	′ ″	′ ″
7 a. m......	—9 22.1	2 46.9	1 21.1	1 25.8
8 a. m......	34.4	34.6	15.9	18.7
9 a. m......	55.5	13.5	3.8	9.7
10 a. m......	57.5	11.5	2.8	8.7
11 a. m......	53.5	15.5	7.6	7.9
Noon	51.6	17.4	7.9	9.5
1 p. m......	47.8	21.2	10.8	10.4
2 p. m......	44.5	24.5	9.9	14.6
3 p. m......	44.8	24.2	11.5	12.7
4 p. m......	46.7	22.3	12.1	10.2
5 p. m......	33.7	35.3	20.8	14.5

The values for the total refraction, r, show the ordinary diurnal variation, the refraction being least soon after 10 a. m., as exhibited in the second figure of the accompanying diagram, where, however, the value of $\frac{1}{2} r$ is represented.

These results from the observed refractions present the anomaly of the refraction at the upper station being greater than the simultaneous refraction at the lower station, except at the afternoon-hours 1, 4, and 5, when the reverse takes place.

Owing to this fact, we do not think it advisable to make any change in the value of a_0.

The angle of refraction for any particular state of the atmosphere with respect to pressure and temperature may be found from the following expressions given by Bauernfeind:

$$\Delta\zeta = \tfrac{1}{2} v\,\psi\left\{1 - \frac{4v - m(5 - 6v)}{3v} p_0\,\psi - (\tfrac{1}{3}p + 1)\,p_0^2\,\psi^2 - \ldots\ldots\right\}$$

$$\Delta\zeta' = \tfrac{1}{2} v\,\psi\left\{1 - \frac{8v + m(5 - 6v)}{3v} p_0\,\psi - (p - 5)\,p_0^2\,\psi^2 - \ldots\ldots\right\}$$

for the lower and upper stations; also the difference of refraction:

$$\Delta\zeta - \Delta\zeta' = \tfrac{1}{3} p_0\,\psi^2\left\{2v + m(5 - 6v) + v(p - 9)\,p_0\,\psi + \ldots\ldots\right\}$$

where $p_0 = \dfrac{\cot\zeta}{m}$ and $p = \dfrac{m(\cos^2\zeta + 1 - v)}{\cos^2\zeta}$ as before.

Applying these formulæ, the angles of refraction at the lower station should be greater by 1″.1 than the corresponding angles at the upper station.

The cause of the apparent anomaly of an observed greater refraction at the upper than at the lower station may be due to difference of station-errors or of that part of the deviation of the plumb-line which is effective in the vertical planes passing through the two stations. This cause would be a constant one. Or it may be due to a difference in the law of decrease of temperature with increase of height; thus, the more rapid the decrease of temperature, the smaller the refraction, and, on the contrary, the slower the decrease of temperature, the greater the refraction. With a sufficiently rapid decrease of temperature the refraction may become zero (and even be negative); with no decrease, or for a constant temperature, the refraction is very large, and will yet increase should the temperature increase (with the height) instead of decrease. Winds at different altitudes, the currents having different temperature, sufficiently explain such occurrences.

Small defects in the absolute value of the atmospheric temperature are of little consequence with regard to measures of height; thus an increase or decrease of 10° Fahrenheit would only produce an increase or decrease of $0^{m}.14$ in the difference of height of Bodega Head and Ross Mountain.

In using the ordinary simple expressions for difference of height, taking the ray of light to be part of an arc of a circle, or the refractions equal at the two stations, which answer well enough for short distances and small heights, a knowledge of the so-called co-efficient of refraction (k) may often be desirable; it is nearly $\frac{1}{2}v$, and may be found for any particular pressure and temperature of the atmosphere by—

$$2\,k = v\,(1 - 2\,p_0\,\psi + (2 - \tfrac{2}{3}p)\,p_0^2\,\psi^2 - \ldots\ldots\ldots.)$$

the letters having the same signification as before. In the present case we find for 9 a. m., at the Bodega Head station, $k = 0.088$, whereas for that hour the reciprocal and simultaneous zenith-distances* give $k = 0.092$, as found by—

$$k = \frac{1}{2} + \frac{180 - (\zeta + \zeta')}{2\,\psi}$$

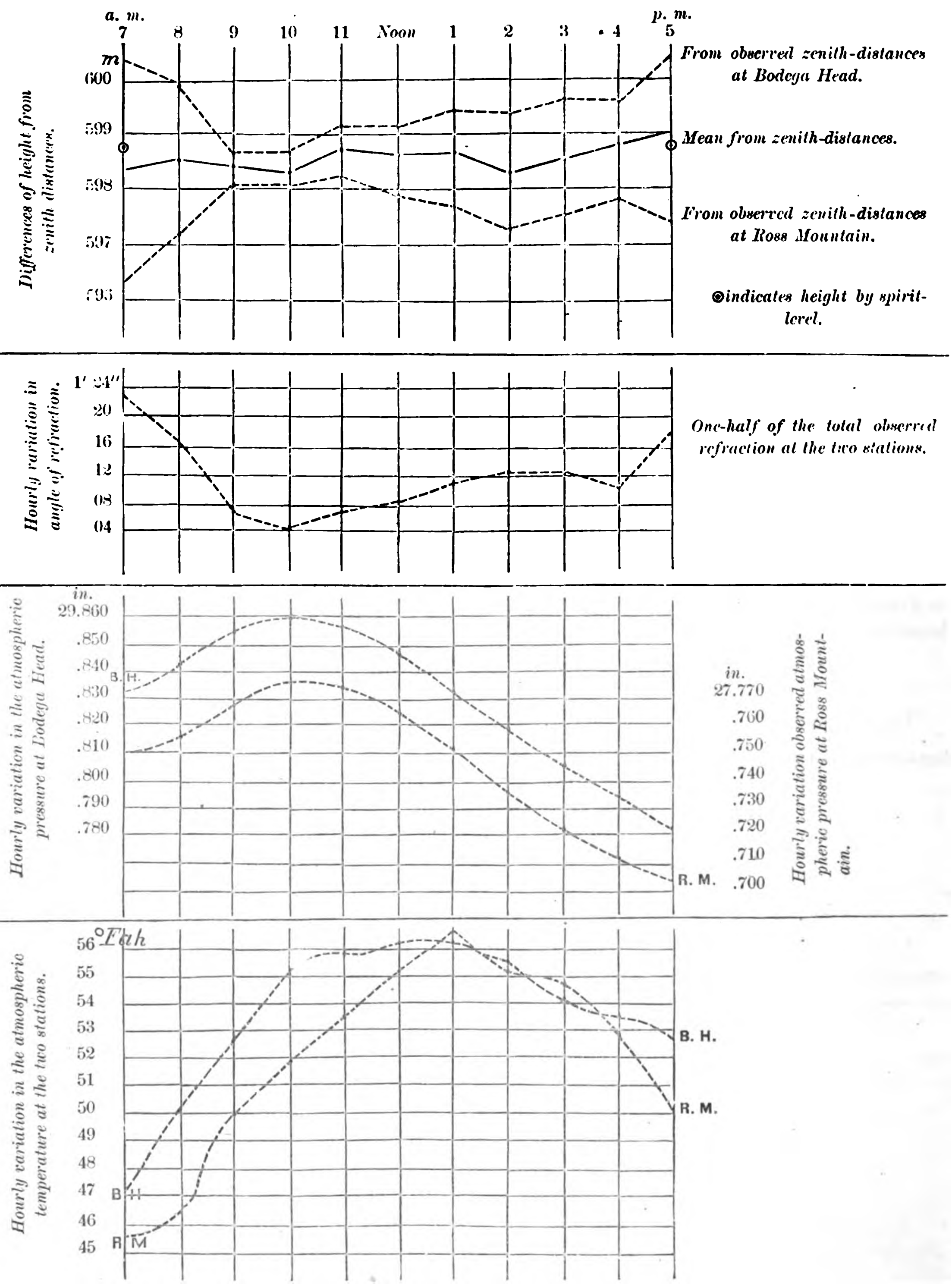
The following table contains the values of $\frac{1}{2}v$ for latitude 38° and for various atmospheric pressures and temperatures:

Pressure.	30° F.	50° F.	70° F.	90° F.
30 inches......	0.094	0.090	0.087	0.084
28 inches......	0.088	0.084	0.081	0.078
26 inches......	0.082	0.078	0.075	0.073
24 inches......	0.076	0.073	0.070	0.067

Further and more extended observations for the daily variation of refraction have been authorized by the Superintendent, and it is to be hoped that these may soon be made.

* The values of k for each hour and the values of Δh found by $\frac{d \sin \frac{1}{2}(\zeta' - \zeta)}{\cos \frac{1}{2}(\zeta' - \zeta + \psi)}$ are contained in the following table:

Hour.	k	Δh	
		m.	
7 a. m......	0.114	598.48	
8 a. m......	.106	.59	
9 a. m......	.092	.42	
10 a. m......	.090	.42	
11 a. m	.093	.72	
Noon	.094	.65	
1 p. m......	.097	.76	
2 p. m......	.099	.48	
3 p. m......	.099	.67	
4 p. m......	.098	598.84	
5 p. m......	.106	599.08	
Mean....	0.099	598.64	± $0^{m}.04$


a. m.
7
8
9
10
11
Noon
1
2
3
4
5
p. m.
m
600
599
598
597
596
Differences of height from zenith distances.
From observed zenith-distances at Bodega Head.
Mean from zenith-distances.
From observed zenith-distances at Ross Mountain.
⊙indicates height by spirit-level.
1′ 24″
20
16
12
08
04
Hourly variation in angle of refraction.
One-half of the total observed refraction at the two stations.
in.
29.860
.850
.840
.830
.820
.810
.800
.790
.780
B. H.
R. M.
Hourly variation in the atmospheric pressure at Bodega Head.
in.
27.770
.760
.750
.740
.730
.720
.710
.700
Hourly variation observed atmospheric pressure at Ross Mountain.
56° Fah
55
54
53
52
51
50
49
48
47
46
45
B. H.
R. M.
Hourly variation in the atmospheric temperature at the two stations.

3.—Results of hourly observations of the atmospheric pressure for difference of height of the stations.

In the present state of barometric hypsometry it is most desirable to make and discuss barometric observations specially undertaken with a view of contributing information respecting the daily and the annual variation in deduced heights. It is only by means of such observations, made in different climates and under different circumstances, that we can secure the foundation for corrections to be applied to computed differences of heights measured barometrically at *any hour* of the day and *any season* of the year.

Ramond, about 1810, appears to have been the first to notice the relation between barometrically-deduced heights and the time of the day when these measures were taken. The annual variation was also indicated by his results. Kreil proposed the use of annual means of pressure and temperature to secure reliable results, especially for the case when the two stations lie horizontally a great distance apart.

Among those who have more recently occupied themselves with this subject may be mentioned Professor Plantamour, Dr. Bauernfeind, Dr. Rühlmann, and Major Williamson, U. S. A. Plantamour's Tables of Corrections have been reproduced in the Meteorological and Physical Tables, published by the Smithsonian Institution (third edition, 1859). Further information will be found in Rühlmann's small but valuable work: "Barometric Measurements of Heights and their Relation to the Constitution of the Atmosphere," Leipzig, 1870.*

Among the conclusions reached are the following: Differences of heights, barometrically determined, appear to attain their maximum value shortly before the time of greatest heat of the day; they decrease rapidly during the afternoon, and slowly during the night, reaching their minimum about one or two hours before sunrise. From the least to the greatest value the rise is rapid. This daily variation in the computed heights appears fully developed only for those days on which the insolation of the ground is complete under a clear sky, and the loss of heat during the night by radiation is not interrupted. On cloudy or windy days the amplitude of the variation is much diminished, without, however, totally disappearing. The magnitude of the daily variation, besides being dependent on the season of the year, is affected by local circumstances, connected with the capacity of the ground for absorption and radiation of heat. Resulting heights, determined from daily or monthly means, also show an annual period; they are found too small in winter and too great in summer. The amplitude of the annual variation is less than that of the daily variation. Heights determined from annual means generally give results differing little from the truth.

Observations are recommended to be made at the following hours, when the daily and annual variations are supposed to pass through zero-value:

In January, at 1 p. m.
In February, at 10 a. m. and 4 p. m.
In March, at 8 a. m. and 6 p. m.
In April, at 7½ a. m. and 7 p. m.
In May, at 7 a. m. and 7 p. m.
In June, at 6½ a. m. and 9½ p. m.
In July, at 6½ a. m. and 9½ p. m.
In August, at 7 a. m. and 7½ p. m.
In September, at 8 a. m. and 6 p. m.
In October, at 10 a. m. and 3½ p. m.
In November, at 10½ a. m. and 2½ p. m.
In December, at no time.

These hours refer to the middle of each month and to an average state of the atmosphere, and must be considered as correct only for the actual circumstances under which they were obtained; how far they apply to our various climatic conditions remains to be ascertained experimentally.

The recognized cause of the daily variation in the computed differences of heights is the defect-

* This pamphlet contains a historical sketch of the development of barometric hypsometry, and includes a compilation of the principal barometric formulae offered by various writers, chronologically arranged; also a table of the literature of this branch of meteorology.

ive mean temperature introduced by the supposition that the mean of the observed temperatures at the two stations equals that of the intervening stratum of air. The daily variation of temperature, under a clear sky, is less the higher we rise above the surface, and is very small in the higher strata. The thermometers, which cannot be elevated sufficiently to place them above the influence of the radiation and conduction of the soil, can, therefore, give but very defective information respecting the temperature of the elevated strata of air, except in the case of an overcast sky. The problem of barometric measures has, therefore, been inverted, and the mean temperature of the air has been computed from the observed pressures, and the difference of altitudes otherwise known or determined. This process leads to a system of corrections to the observed temperatures to be applied in the computation of ordinary hypsometric measures by means of the barometer.

It matters comparatively little which of the generally-recognized barometric formulæ is used; for the case in hand we select from the class of formulæ which introduce a distinct term for observed humidity, that given by Dr. Rühlmann, for which see his work on Barometric Measurements of Heights (Leipzig, 1870), or Astronomical Tables and Formulae, by Dr. C. F. W. Peters (Hamburg, 1871). Plantamour's and Bauernfeind's formulæ give almost identical results, which, in the present case, are about three-fourths of a meter in excess; on the other hand, Laplace's, Baily's, and Loomis' formulae, all based upon an average degree of humidity, give results about one and one-half meter in defect of the result by Rühlmann's formula. The effect on the calculated height of the term, involving the hygrometric state of the air, is comparatively small; in the present case the result for complete saturation being $2^{m}.7$ greater than the results supposing absolute dryness.

Let—

h = difference in height, expressed in meters;

b', b'' = atmospheric pressure at the lower and upper stations, both readings reduced to refer the temperature of the mercury to that of freezing water; in the term involving the vapor-pressure b' and b'' should be expressed in millimeters;

t', t'' = atmospheric temperature, expressed in centigrade scale, at the lower and upper stations;

σ', σ'' = the vapor-pressure, expressed in millimeters, at the lower and upper stations;

z = height of lower station above the sea-level; and

φ = mean latitude of the stations:

then—

$$h = 18400.2\left(1.00157 + 0.003675\,\frac{t'+t''}{2}\right)\left(1 + 0.378\,\frac{\frac{\sigma'}{b'}+\frac{\sigma''}{b''}}{2}\right)$$

$$\times\ (1 + 0.002623\cos 2\varphi)\left(1 + \frac{2z+h}{6378150}\right)\log\frac{b'}{b''}$$

The logarithms of these terms are tabulated,* and putting for convenience—

$$\log\left\{18400.2\left(1.00157 + 0.003675\,\frac{t'+t''}{2}\right)\right\} = \mathrm{A}$$

$$\log\left\{\log b' - \log b''\right\} = \mathrm{B}$$

$$\log\left\{1 + \frac{0.378}{2}\left(\frac{\sigma'}{b'} + \frac{\sigma''}{b''}\right)\right\} = \mathrm{C}$$

$$\log\left\{1 + 0.002623\cos 2\varphi\right\} = \mathrm{D}$$

$$\log\left\{1 + \frac{2z+h}{637815}\right\} = \mathrm{E}$$

we have—

$$\log h = \mathrm{A} + \mathrm{B} + \mathrm{C} + \mathrm{D} + \mathrm{E}$$

If T and T′ = temperature of dry and wet bulb, e = maximum vapor-tension at T′; then

$$\sigma = e - 0.0008\,(\mathrm{T} - \mathrm{T}')\,b$$

and in case the wet bulb is coated with ice,

$$\sigma = e - 0.00069\,(\mathrm{T} - \mathrm{T}')\,b$$

* Rühlmann's Table I (also that given in Peters' tables) requires a small correction, easily applied, in the last place of decimals, to produce perfect accord with the numbers in the formula. It has been supplied in the present application.

The mean value of σ or $\frac{\sigma' + \sigma''}{2}$ and the mean pressure $b = \frac{b' + b''}{2}$ form the arguments for the table giving the value of C with sufficient approximation.

The following table contains the resulting differences of height between Bodega Head and Ross Mountain for each of the observing-hours, and their excess (indicated by a minus sign) over the true difference, as found by the spirit-level:

Hour.	h	$598.74 - h$.
	m.	m.
7 a. m	598. 80	− 0. 06
8 a. m	600. 98	− 2. 24
9 a. m	605. 52	− 6. 78
10 a. m	607. 65	− 8. 91
11 a. m	608. 84	− 10. 10
Noon	609. 17	− 10. 43
1 p. m	610. 34	− 11. 60
2 p. m	609. 73	− 10. 99
3 p. m	608. 94	− 10. 20
4 p. m	607. 98	− 9. 24
5 p. m	604. 32	− 5. 58

The small effect of variations in moisture in these results has already been stated; to ascertain effects of small changes in pressure and in temperature we have—

$$d\,h = h\left\{\frac{a\,d\,\tau}{1 + a\,\tau} + \mathrm{M}\frac{d\,b'}{\log b' \quad \log b}\left(\frac{1}{b} + \frac{1}{b''}\right)\right\}$$

where—

$\tau \;= \frac{1}{2}(t' + t'')$;
$a \;= 0.003675$;
M $=$ modulus of common logarithms; and
$d\,b'' \doteq - d\,b'$.

Supposing an error in the reading of the barometers of 0.004 inch, or 0.1 millimeter nearly, to have been committed at each of the stations (but of opposite signs), we find $dh = 2.3$ meters; hence, in the mean value from five days of observations we may expect a remaining uncertainty of nearly one meter.

Supposing an error in the reading of the thermometer of $\frac{1}{3}$° Fahrenheit, nearly 0°.2 centigrade, we have $dh = 0.4$ metre, showing that the uncertainty in any one of the above hourly results arising from imperfect readings of instruments may be taken as $\frac{1}{600}$ of the height nearly.

The computed differences of height for each hour are shown in the accompanying diagram, to which has been added the resulting vapor-pressure at the two stations, as computed from Major Williamson's table.* The deduced vapor-pressures, as well as the observed temperatures at the two stations, are strictly local results, and give no true indication of the humidity and temperature of the *intervening stratum* of air.

The true difference of height and the pressure at the two stations being known, we find the mean temperature of the air depending upon these data by—

$$\tau = \frac{1}{a}\left(\frac{h}{k\,(\log b' - \log b'')} \quad 1\right)$$

where k represents the constant in the approximate expression—

$$h = k\,(1 + a\,\tau)\log\frac{b'}{b''}$$

But it is more convenient and accurate to make use of the tables, forming the values $\frac{\log h}{\mathrm{B} + \mathrm{C} + \mathrm{D} + \mathrm{E}}$,

* Professional Papers of the Corps of Engineers, United States Army, No. 15, New York, 1868.

and entering the first table, which gives the value of 2τ directly. Converting the hourly values of τ so found into their equivalents in Fahrenheit degrees, we obtain the following numbers:

Hour.	Observed mean temperature at Bodega Head and Ross Mountain.	Computed temperature of intervening stratum of air.	Apparent temperature correction.	Correction by Plantamour's table.
	°	°	°	°
7 a. m......	46.4 F.	46.4 F.	0.0 F.	+1.0 F.
8 a. m......	48.4	46.4	−2.0	−0.6
9 a. m......	51.4	45.6	−5.8	−2.6
10 a. m......	53.4	46.0	−7.4	−4.2
11 a. m......	54.7	46.2	−8.5	−5.1
Noon	55.6	46.8	−8.8	−5.8
1 p. m......	56.3	46.4	−9.9	−6.0
2 p. m......	55.2	46.0	−9.2	−5.5
3 p. m......	54.5	45.9	−8.6	−4.6
4 p. m......	53.2	45.7	−7.5	−3.3
5 p. m......	51.4	46.6	−4.8	−2.0

The numbers in the last column are interpolations from Plantamour's Table XI, p. D. 82, of third edition of the Smithsonian Meteorological and Physical Tables; they refer to March 24, and were converted into degrees of Fahrenheit.

We thus arrive at the remarkable result that the temperature of the intervening stratum of air is nearly constant, viz, 46°.2, and shows apparently no trace of a daily variation, the rays of the sun passing through without sensibly heating it. The daily variation of temperature, therefore, would seem to be confined mainly to the layer of air in contact and close proximity to the earth's surface. The corrections derived from Plantamour's table (deduced from observations at Geneva and the great Saint Bernard) are smaller than those deduced from our observations, but the latter refer to a clear sky (the heliotropes having been seen every hour). To make Plantamour's corrections answer for our case, they require to be increased by two-thirds of their amount; for the case of an overcast sky, they must be diminished possibly by one-half or more. The one-third of the total solar radiation, which may be absorbed by the atmosphere, is probably consumed by the processes of expansion and evaporation, and thus gives no sensible heat. In the present case, however, the daily variation of temperature is very small, owing to the proximity of the ocean, and different and apparently less anomalous results may be expected for stations farther removed from the coast.

To estimate the effect of a small error in the observed pressure on the deduced mean temperature, and supposing, as before, $d\,b'' = -\,d\,b'$, we have, from

$$d\,\tau = \frac{M\,(1 + \alpha\,\tau)}{\alpha\,(\log b' - \log b'')}\left(\frac{1}{b'} + \frac{1}{b''}\right) d\,b'$$

the relation $d\,\tau = 10.8\ d\,b'$; hence, for $d\,b' = 0.1$ millimeter, $d\,\tau = 1°.1$ centigrade, or nearly 2° Fahrenheit, which shows the extreme sensitiveness of the operation.

If the barometric observations *alone* had been available, the safest result that might have been deduced from them would have been that interpolated for the epoch $7\frac{3}{4}$ a. m., which is $600^{m}.5$, and $1^{m}.8$ in excess of the true value. Error about $\frac{1}{333}$ of the difference of heights.

Addendum.—The approximate and very convenient formula, specially applicable to aneroid barometers, and giving the difference of height in feet, viz:

$$\Delta\,h = 54500\,\frac{\text{diff. of readings}}{\text{sum of readings}} \pm 10\text{ ft.} \pm \frac{\Delta\,h}{200},$$

gives for Ross Mountain and Bodega Head $\Delta\,h = 54500 + \frac{2.083}{57.577} = 1971.7$ feet. This formula

supposes the temperature of the intervening air to be 55° Fahr. For every degree of mean temperature in excess $\frac{1}{450}$ of Δh is to be added (or subtracted for every degree in defect.) In our case, the temperature of the air is 52°.8 Fahr., hence the correction — 9.6 feet and the resulting difference of height 1962 feet $\pm \sqrt{10^2 + (9.8)^2}$ or $\pm$ 14 feet. The true difference is 1964.4 feet. The approximate formula applies to differences of heights not exceeding about 3000 feet.

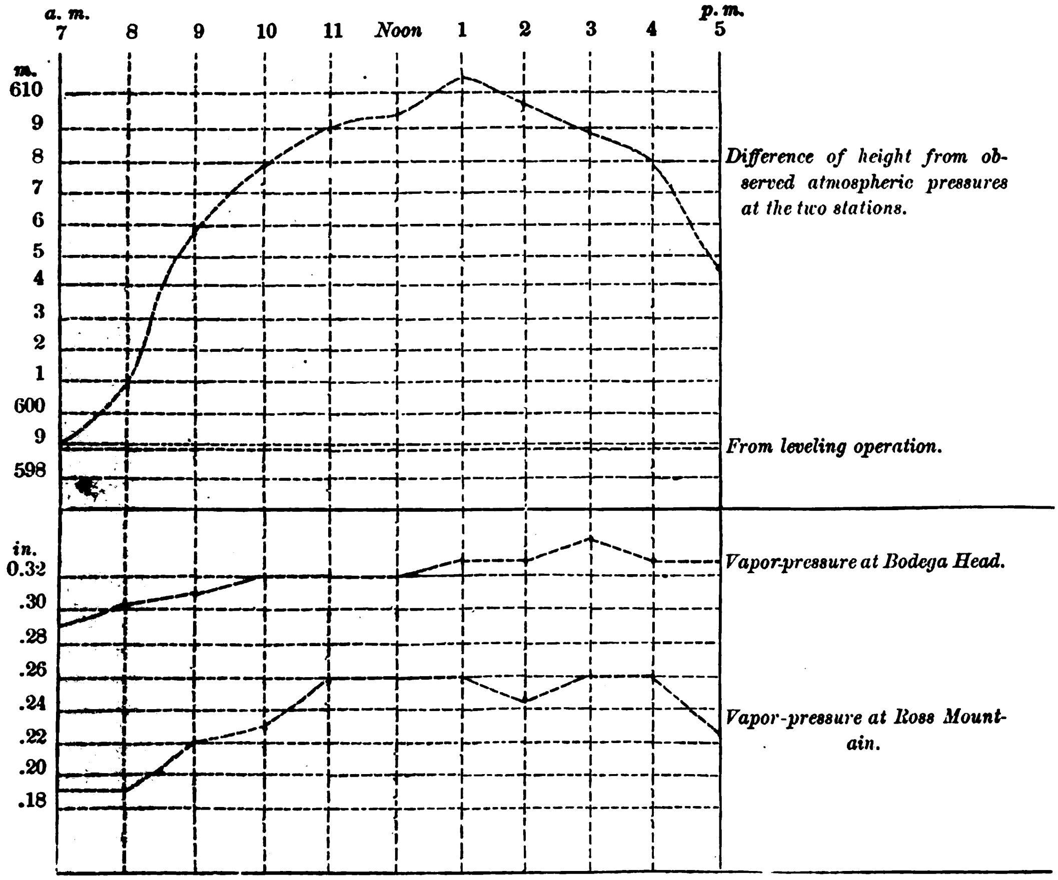


Table of logarithms of radius of curvature to the earth's surface, for various latitudes and azimuths, based upon Clarke's ellipsoid of rotation* (1866), *and for metric unit.*

	Azimuth.	LATITUDE.						
		24°	26°	28°	30°	32°	34°	36°
	°							
Meridian......	0	6. 802479	6. 802597	6. 802722	6. 802852	6. 802988	6. 803129	6. 803274
	5	2498	2615	2739	2869	3004	3145	3289
	10	2553	2669	2791	2919	3052	3190	3332
	15	2644	2756	2875	3000	3130	3265	3404
	20	2766	2875	2990	3111	3236	3366	3500
	30	3093	3192	3296	3405	3518	3636	3757
	40	3496	3580	3671	3766	3864	3967	4072
	50	3923	3994	4070	4150	4233	4319	4407
	60	4325	4384	4446	4512	4580	4650	4723
	70	4653	4702	4753	4807	4863	4921	4980
	75	4776	4822	4869	4918	4969	5022	5076
	80	4867	4909	4953	4999	5047	5097	5148
	85	4923	4963	5006	5049	5096	5143	5192
Prime vertical.	90	6. 804942	6. 804981	6. 805023	6. 805066	6. 805112	6. 805159	6. 805207
		38°	40°	42°	44°	46°	48°	50°
Meridian......	0	6. 803422	6. 803573	6. 803726	6. 803880	6. 804035	6. 804189	6. 804342
	5	3436	3586	3739	3892	4045	4199	4351
	10	3478	3626	3775	3926	4077	4228	4378
	15	3546	3690	3835	3982	4130	4277	4423
	20	3637	3776	3917	4059	4201	4343	4484
	30	3880	4006	4133	4262	4391	4519	4647
	40	4179	4289	4400	4511	4623	4735	4846
	50	4498	4590	4683	4777	4871	4965	5058
	60	4797	4873	4949	5025	5104	5181	5257
	70	5041	5104	5166	5229	5293	5357	5420
	75	5133	5190	5248	5307	5364	5423	5481
	80	5201	5254	5308	5363	5417	5472	5526
	85	5242	5294	5345	5397	5450	5502	5554
Prime vertical.	90	6. 805256	6. 805307	6. 805358	6. 805409	6. 805460	6. 805512	6. 805563

* A more extended table will be found appended to the third contribution (Appendix No. 18) relating to hypsometry.

APPENDIX No. 17.

OBSERVATIONS OF ATMOSPHERIC REFRACTION—CONTRIBUTION No. II.

DETERMINATION OF SEVERAL HEIGHTS BY THE SPIRIT-LEVEL, AND MEASURES OF REFRACTION BY ZENITH-DISTANCES, ALSO OBSERVATIONS OF THE BAROMETER, AT RAGGED MOUNTAIN, MAINE, IN JULY, AUGUST, AND SEPTEMBER, 1874, BY F. W. PERKINS, SUBASSISTANT. RESULTS DEDUCED AND REPORTED BY CHARLES A. SCHOTT, ASSISTANT.

FEBRUARY 23, 1876.

In connection with the determination of the heights, by means of the spirit-level, of several trigonometrical stations on the coast of Maine, a series of special observations were made for amount and for daily variation of the atmospheric refraction, comprising not only the hours of the day but also those of the night. The zenith-distances measured at Ragged Mountain furnish not less than 227 hourly determinations of the refraction, and along lines of various lengths and azimuths. The meteorological observations at Ragged Mountain include the atmospheric pressure, temperature, humidity, direction and force of wind, kind and amount of clouds, and the condition of the atmosphere. Similar observations were made at Mount Desert and at White Head Light. Ragged Mountain is situated near the ocean, on the west side of Penobscot Bay. Its position, as well as those of the other stations included in Mr. Perkins' operations, is shown on progress sketch No. 4. The work was conducted under special instructions given to the observer by Assistant R. D. Cutts.

The first series of special observations for atmospheric refraction, undertaken by the survey, was made in California, near the coast, by Assistant G. Davidson in 1860. An account of these observations, in detail, and a discussion of the results deduced from them is contained in Appendix No. 11, Coast Survey Report of 1871, reprinted as Appendix No. 16 of this report. The present series differs from this in the occupation of but one station, including measures during night, and in the use of long lines.

It has been determined to ascertain by means of the spirit-level the heights of a number of primary triangulation stations, situated near the Atlantic and consequently easily accessible from tide-water, to serve as *base-stations* for the determination of heights of stations in the interior by means of the zenith-distances, reciprocal but non-simultaneous, which have accumulated during the progress of the work; and it was principally with this view that the operations in charge of Mr. Perkins were undertaken. We shall first give the results from spirit-levelings, next those deduced from the zenith-distances, and conclude with a summary of the meteorological results.

A.—RESULTS OF THE OPERATIONS BY SPIRIT-LEVEL EXECUTED NEAR THE ENTRANCE TO PENOBSCOT BAY IN 1874.

The Würdemann pivot spirit-level, C. S. No. 26, was used for all the lines, and a similar instrument, C. S. No. 21, was used in 1875 in the check leveling of a part of the line to Ragged, which was not quite satisfactory in the preceding year. Each line was leveled twice, in opposite directions, the difference in the results amounting to a few millimeters. The instrument was adjusted each day before commencing operations, and at other times when needed. Three readings of the staff were taken, one on each of the three fixed threads in the focus of the telescope, by which means the distance of the staff became known, and corrections to the observed difference of heights for curvature and refraction for unequal distances could be applied; the level was read in connection with the pointing and a small correction applied when needed for deviation of line of collimation from horizontality. The staves were divided metrically and were of standard length. The levels and results are referred, by means of tidal bench-marks, to the half-tide level or mean surface of the Atlantic. This level is capable of being ascertained with more precision and in briefer time

than either the mean low or mean high water level, especially in places where the diurnal inequality of the tides has a sensible value.

Resulting heights above the mean level of the Atlantic.

	Meters.		Feet.
1. Tidal bench-mark at Camden Harbor	0.046	or	0.15
Bench-mark at Eaton's House	69.849		229.16
Ragged Mountain △, *ground*	396.585		1301.14
cistern of barometer	393.595		1291.33
vertical circle No. 100	398.267		1306.66
vertical circle No. 37	398.275		1306.69
2. Tidal bench-mark at Bar Harbor	3.155		10.35
Mount Desert △, *ground*	464.884		1525.22
top of mountain	465.414		1526.96
heliotrope	466.243		1529.68
cistern of barometer	468.221		1536.17
ridge-pole, hotel	469.883		1541.62
3. *Matinicus West Light.*			
bench-mark at light-house	11.415		37.45
ridge-pole, keeper's house	21.595		70.85
lower parapet of light-house	25.162		82.55
focal plane of light	27.554		90.40
roof of light-house	28.804		94.50
4. *Owl's Head Light.*			
bench-mark on tower	25.877		84.90
lower parapet, edge of black on lantern	30.388		99.70
focal plane of light	32.003		105.00
gutter of roof of light-house	33.009		108.30
5. *White Head Light.*			
bench-mark on tower	13.535		44.41
cistern of barometer	18.334		60.15
ridge-pole, keeper's house	22.053		72.35
lower parapet	22.435		73.61
focal plane of light	24.173		79.31
roof of light-house	25.087		82.31
6. *Tenant's Harbor Light.*			
bench-mark on tower	13.510		44.33
parapet	19.637		64.43
focal plane of light	21.008		68.93
edge of roof of light-house	21.679		71.13
ridge-pole, keeper's house	22.273		73.08

To the above may be added the height of Sebattis △, ground, viz: 243.740 meters (799.68 feet), as leveled by Assistant G. A. Fairfield in 1872, who referred it to the half-tide level of Merrymeeting Bay. I propose to add 0.250 meter to refer the height to the mean level of the ocean. Height of Sebattis △, ground 243.990 meters, and of crotch on signal, as observed upon by Mr. Perkins, 255.344 meters.

The geographical positions of these stations, derived from triangulation, are as follows:

	Latitude.			Longitude.		
	°	′	″	°	′	″
Ragged Mountain △	44	12	44.25	69	09	03.47
Mount Desert △	44	21	04.13	68	13	35.30
Matinicus West Light	43	47	01.44	68	51	19.07
Owl's Head Light	44	05	31.04	69	02	38.87
White Head Light	43	58	42.53	69	07	27.52
Tenant Harbor Light	43	57	39.18	69	11	05.68
Sebattis △	44	08	36.70	70	04	42.37

The azimuths and distances from Ragged △ to each of these stations are:

	Azimuth.			Distance.	
	°	′	″	*Meters.*	*St. miles.*
To Mount Desert △	257	52	06.55	75384.39 =	46.84
To Matinicus Light	333	25	22	53190.0	33.06
To Owl's Head Light	327	22	35	15867.4	9.86
To White Head Light	355	17	40	26064.4	16.19
To Tenant Harbor Light	5	34	14	28063.9	17.44
To Sebattis △	84	26	28.00	74549.37	46.33

B.—Results of observations of zenith-distances at Ragged Mountain for the measure of atmospheric refraction.

The observer aimed at hourly observations of the zenith-distance of one or another of the above objects; at night a light-house was exclusively observed. From July 22 to August 6 inclusive he used the 12-inch Gambey Vertical Circle, C. S. No. 37; after this date, to the close of the work, the 10-inch Vertical Circle, C. S. No. 100. The observations were taken in sets of five repetitions of the double-zenith distance, one set just before and another just after each full hour: each hourly tabular result thus consists of 20 measures of the zenith-distance—corrected for want of level, for which there were five complete readings to each set for Circle No. 100. Circle No. 37 was kept level as far as practicable. The tabular resulting zenith-distances ζ are reduced for height of instrument at Ragged Mountain, also corrected when necessary for height of object observed upon; they are referred to the triangulation stations △ at Mount Desert and Sebattis, and to the focal plane of the lights.

Resulting zenith-distances observed at Ragged Mountain in 1874.

MOUNT DESERT, $\zeta = 90° 13' +$											
Hour.	July			August					September		
	22	23	31	3	4	5	25	26	1	8	12
	″	″	″	″	″	″	″	″	″	″	″
5 a. m.	....	50.9	42.5	....	....	46.1	....	....	....	....	....
6 a. m.	15.6	45.7	37.7	....	....	56.3	32.3	16.6	48.0	46.5	45.2
7 a. m.	07.9	34.1	29.3	....	....	52.1	23.5	23.3	42.9	32.8	34.7
8 a. m.	....	44.0	36.3	....	....	45.4	36.5	24.9	64.7	36.5	29.0
9 a. m.	....	30.4	41.5	....	....	58.8	47.4	39.8	77.8	56.7	62.0
10 a. m.	....	47.9	58.1	....	....	71.3	56.0	....	83.1	75.8	70.3
11 a. m.	....	44.7	56.6	....	72.6	68.2	65.3	....	83.0	77.6	73.0
Noon	....	37.3	55.2	....	67.1	65.7	68.4	....	84.2	80.0	73.0
1 p. m.	....	42.4	44.8	....	69.8	66.6	66.4	....	83.2	78.8	74.2
2 p. m.	....	43.8	50.6	....	65.4	....	57.9	....	75.7	....	75.6
3 p. m.	....	46.0	46.8	....	67.6	....	41.9	....	75.4	....	73.3
4 p. m.	....	38.5	21.2	....	63.8	....	43.8	....	....	....	71.3
5 p. m.	....	29.9	10.1	....	60.8	....	33.8	....	....	....	68.1
6 p. m.	....	33.2	....	70.3	59.6	....	13.8	....	....	60.4	67.2
7 p. m.	....	44.1	....	67.1	64.8	....	....	....	....	....	....

Resulting zenith-distances observed at Ragged Mountain in 1874—Continued.

MATINICUS WEST LIGHT, $\zeta = 90° 35' +$

Hour.	August							September	
	3	4	5	19	20	22	23	7	8
	"	"	"	"	"	"	"	"	"
Midn't..	....	29.0	11.2	....	−02.9	....	40.1	....	19.5
1 a. m..	....	21.8	27.1	....	+11.2	....	44.3	....	08.6
2 a. m ..	....	21.4	21.0	....	+07.7	....	40.2	....	14.1
3 a. m..	....	20.0	32.1	....	−03.2	....	52.1	....	14.5
4 a. m ..	....	26.0	25.4	....	....	....	24.5	....	....
5 a. m..	....	....	....	....	....	....	47.4	....	12.1
6 p. m..	....	....	....	22.0	....	....	....	....	....
7 p. m ..	....	....	....	....	....	....	....	53.9	....
8 p. m..	18.8	24.3	31.6	02.4	....	40.2	....	34.7	....
9 p. m..	23.0	33.9	....	−02.8	....	49.1	....	31.7	....
10 p. m..	22.2	27.8	....	−00.9	....	49.9	....	27.7	....
11 p. m..	31.9	28.2	....	−13.9	....	53.6	....	29.5	....

OWL'S HEAD LIGHT, $\zeta = 91° 22' +$ / **WHITE HEAD LIGHT, $\zeta = 90° 55' +$**

Hour.	July		Aug.	Sept.	August					September		
	27	30	29	3	3	22	24	27	28	2	5	7
	"	"	"	"	"	"	"	"	"	"	"	"
6 a. m	....	....	25.8	....	19.2	+02.2	+01.3	....	−23.4	+10.7	....	....
7 a. m..	....	....	....	29.0	18.4	−01.9	05.3	−12.6	−22.1	....	−20.2	+00.8
8 a. m..	....	58.0	....	....	21.3	+04.4	17.5	−11.8	....	20.5	....	....
9 a. m..	60.1	63.3	....	....	17.7	+20.7	19.4	....	....	....	....	....
10 a. m..	59.4	65.0	....	....	17.5	....	21.4	....	....	23.2	....	....
11 a. m..	60.2	65.8	....	....	19.5	....	18.5	....	....	....	....	....
Noon ..	59.0	62.9	....	....	....	....	23.7	....	....	20.9	....	....
1 p. m..	60.3	64.5	....	....	....	....	26.5	....	....	....	....	....
2 p. m..	59.3	60.3	....	....	....	....	22.7	....	....	21.7	....	....
3 p. m..	61.4	65.2	....	....	....	....	23.5	....	....	....	....	....
4 p. m..	57.8	62.6	....	....	....	....	19.7	....	....	17.8	....	....
5 p. m..	55.8	57.0	....	....	....	....	17.6	....	....	....	....	....
6 p. m..	52.6	51.3	....	....	....	....	+09.7	....	....	+03.4	....	....
7 p. m..	....	55.1	....	....	....	....	−03.8	....	....	....	....	....

TENANT'S HARBOR LIGHT, $\zeta = 90° 52' +$

Hour.	August		September			
	6	22	2	5	7	9
	"	"	"	"	"	"
6 a. m..	19.3	....	....	−01.4	17.1	28.7
7 a. m..	26.5	....	27.3	....	....	32.9
8 a. m..	....	....	....	....	22.0	36.4
9 a. m..	....	....	43.5	....	....	....
10 a. m..	....	....	....	....	....	....
11 a. m..	....	....	43.7	....	....	....
Noon ..	....	....	....	....	....	....
1 p. m..	....	....	41.2	....	....	....
2 p. m..	....	....	....	....	....	....
3 p. m..	....	....	41.0	....	....	....
4 p. m..	....	41.6	....	....	....	....
5 p. m..	....	40.0	29.1	....	....	....
6 p. m..	....	35.0	....	....	....	....
7 p. m..	....	28.2	....	....	....	....

SEBATTIS, $\zeta = 90° 23' +$

Hour.	Sept.
	9
	"
6½ a. m	23.6

The most direct method of testing these observations and of deducing from them the coefficient of refraction is to compute the *true* zenith-distances Z at Ragged Mountain, as if no refraction existed, and to compare therewith the observed zenith-distances ζ, which gives the value of m by a simple relation.

Let—

Z Z′ be the true zenith-distances in case of no refraction;
H H′ the known heights, by spirit-level, of these two stations;
s ρ ψ the length, radius of curvature, and angle subtended of the arc of a great circle joining the stations respectively; then—

$$\begin{cases} \frac{1}{2}(Z' + Z) = 90^\circ + \frac{1}{2}\psi \\ \frac{1}{2}(Z' - Z) = \tan^{-1}\left(\frac{H' - H}{s}\left\{1 - \frac{H' + H}{2\rho} - \frac{s^2}{12\,\rho^2}\right\}\right) \end{cases} \text{ also } m = \frac{Z - \zeta}{\psi} \text{ and } m = \frac{Z' - \zeta'}{\psi}$$

With our data and the relation $\psi = \frac{s}{\rho \text{ arc } 1''}$ we compute the following zenith-distances Z at Ragged:

	°	′	″
True zenith-distance Z to Mount Desert	90	17	10.3
True zenith-distance Z to Matinicus Light	90	38	12.1
True zenith-distance Z to Owl's Head Light	91	23	15.9
True zenith-distance Z to White Head Light	90	56	09.3
True zenith-distance Z to Tenant's Harbor Light	90	53	35.0
True zenith-distance Z to Sebattis	90	27	06.4

Correction of observed zenith-distances for *local deflection* of the plumb-line.—The preceding geodetic computations, being based upon an assumed ellipsoidal figure of the earth, refer to the geodetic zenith, whereas the observed zenith-distances refer to the disturbed or astronomical zenith, the same as the observations for latitude and azimuth made at Ragged in connection with the triangulation. Referring for further explanation to Coast Survey Report for 1869, Appendix No. 7, we have—

$\Delta\varphi$ = astronomical minus geodetic latitude $= -0''.90 \pm 0''.04$, deflection in the meridian,
$\Delta\alpha$ = astronomical minus geodetic azimuth $= -0''.81 \pm 0''.27$, deflection in azimuth;

hence deflection of the zenith in the plane of the prime vertical

$$\Delta \text{pv} = -\Delta\alpha \cot\varphi = +0''.83$$

and total deflection of the zenith

$$\Delta Z = \sqrt{(.90)^2 + (.83)^2} = 1''.22$$

and the azimuth of the disturbed zenith is $\alpha_z = 42^\circ.7$ nearly*. The correction to the observed zenith-distance is found by $1''.22 \cos\varepsilon$, the angle ε being known from the azimuth α_z and the azimuth of each line. We have correction to observed zenith-distance—

	″
ζ of Mount Desert	$= -1.0$
of Matinicus Light	$+0.4$
of Owl's Head Light	$+0.3$
of White Head Light	$+0.8$
of Tenant's Harbor Light	$+1.0$
of Sebattis	$+0.9$

Instead of applying these corrections directly to each ζ it was more convenient to apply them with their signs reversed to their respective Z as computed above. This being done the following table of resulting values of the co-efficient m was obtained:

* In this case the disturbed zenith is to the southward and westward of the geodetic or undisturbed zenith at Ragged.

Resulting coefficient of refraction from observations of zenith-distances at Ragged Mountain, coast of Maine, in July, August, and September, 1874.

Hour.	JULY					AUGUST														
	22	23	27	30	31	3	3	3	4	4	5	5	6	19	20	22	22	22	23	24
	Mount Desert.	Mount Desert.	Owl's Head Light.	Owl's Head Light.	Mount Desert.	White Head Light.	Mount Desert.	Matinicus Light.	Mount Desert.	Matinicus Light.	Mount Desert.	Matinicus Light.	Tenant Harbor Lt.	Matinicus Light.	Matinicus Light.	White Head Light.	Tenant Harbor Lt.	Matinicus Light.	Matinicus Light.	White Head Light.
Midn't										.0945		.1048			.1130				.0880	
1 a. m.										.0986		.0956			.1048				.0856	
2 a. m.										.0989		.0991			.1069				.0880	
3 a. m.										.0997		.0926			.1132				.0811	
4 a. m.										.0962		.0966							.0971	
5 a. m.		.0823			.0858						.0843								.0838	
6 a. m.	.0968	.0844			.0877	.0584					.0800		.0821			.0785				.0796
7 a. m.	.1000	.0892			.0912	.0593					.0818		.0742			.0834				.0748
8 a. m.		.0852		.0343	.0883	.0559					.0846					.0759				.0604
9 a. m.		.0907	.0302	.0240	.0862	.0602					.0791					.0566				.0582
10 a. m.		.0835	.0315	.0206	.0794	.0604					.0739									.0558
11 a. m.		.0849	.0300	.0191	.0800	.0580			.0734		.0752									.0592
Noon		.0879	.0323	.0247	.0806				.0757		.0762									.0531
1 p. m.		.0858	.0298	.0216	.0848				.0746		.0759									.0497
2 p. m.		.0853	.0308	.0298	.0825				.0764											.0542
3 p. m.		.0843	.0277	.0203	.0840				.0755											.0533
4 p. m.		.0874	.0347	.0253	.0945				.0770								.0576			.0578
5 p. m.		.0909	.0386	.0362	.0991				.0783								.0594			.0603
6 p. m.		.0896	.0448	.0473			.0744		.0787					.0985			.0649			.0696
7 p. m.		.0851		.0399			.0757		.0766								.0723			.0856
8 p. m.								.1003		.0972		.0930		.1099				.0880		
9 p. m.								.0980		.0916				.1129				.0828		
10 p. m.								.0984		.0952				.1119				.0823		
11 p. m.								.0928		.0949				.1193				.0802		

Hour.	AUGUST					SEPTEMBER													
	25	26	27	28	29	1	2	2	3	5	5	7	7	7	8	8	9	9	12
	Mount Desert.	Mount Desert.	White Head Light.	White Head Light.	Owl's Head Light.	Mount Desert.	White Head Light.	Tenant Harbor Lt.	Owl's Head Light.	White Head Light.	Tenant Harbor Lt.	White Head Light.	Tenant Harbor Lt.	Matinicus Light.	Mount Desert.	Matinicus Light.	Tenant Harbor Lt.	Sebattis.	Mount Desert.
Midnight																.1000			
1 a. m.																.1063			
2 a. m.																.1031			
3 a. m.																.1029			
4 a. m.																			
5 a. m.																.1042			
6 a. m.	.0899	.0964		.1088	.0970	.0835	.0684				.1049		.0846		.0841		.0718	.0918	.0847
7 a. m.	.0936	.0936	.0960	.1073		.0856		.0733	.0907	.1050		.0802			.0898		.0672		.0890
8 a. m.	.0882	.0930	.0951			.0766	.0568						.0792		.0882		.0633		.0913
9 a. m.	.0838	.0869				.0713		.0555							.0799				.0778
10 a. m.	.0802					.0691	.0536								.0721				.0743
11 a. m.	.0764					.0691		.0553							.0713				.0732
Noon	.0751					.0686	.0564								.0704				.0732
1 p. m.	.0759					.0691		.0581							.0708				.0727
2 p. m.	.0794					.0721	.0554												.0722
3 p. m.	.0860					.0722		.0583											.0731
4 p. m.	.0852						.0600												.0739
5 p. m.	.0894							.0714											.0753
6 p. m.	.0975						.0771								.0784				.0756
7 p. m.														.0800					
8 p. m.														.0912					
9 p. m.														.0929					
10 p. m.														.0952					
11 p. m.														.0942					

The combination of the foregoing tabular results of the coefficient of refraction to a *systematic* series, showing the law of the daily variation, is a matter of some difficulty, considering the broken character of the individual daily series, and the fact that the day observations are but very slightly connected with the night observations.

In the first place, we recognize the fact that the refraction varies or may vary more from day to day—though frequently it may be nearly constant for days or weeks, showing either a normal, an extremely high, or an extremely low value—than the amount of the ordinary range of the diurnal variation. Thus, on July 27 and 30, the refraction was less than one-half its normal value, yet clearly exhibiting the daily variation, whose range ordinarily amounts to about one-third of the mean value of the coefficient. We may thus conceive our problem to be as follows: The scattered hourly values on each day present a portion of the daily variation, more or less conforming to the mean type, yet collectively either above or below it, and requiring an index-correction to bring them, as it were, to the proper average level. To do this strictly we have to compare the hourly results of each day with the corresponding results of every other day, and from the combination of all these comparisons to deduce that system of differences or index corrections to each day, which is found by application of the method of least squares.* However, on account of the irregularity and loose connection of our individual series, nothing more than a close approximation to this most probable result is needed. It was effected as follows: The six most complete series between the hours 6 a. m. and 6 p. m. were united to a mean; to this mean, series were referred by means of differences, and then incorporated with it every other series successively in the order of length of daily series. This produced the first approximate series, in which 211 values were used. It only served for ascertaining the final index-correction for each day. A table of differences was formed by comparing every observed value with its corresponding value in the approximate series, and the mean of the differences on each day gave the index-correction to all the observations on that day. After applying these corrections, the respective hourly means were taken. In the following table column 1 contains the reference to the hours; column 2 contains the approximate series of the values of refraction; column 3 the mean systematic series; column 4 the number of days of observations for each hourly value; and columns 5 and 6 the final results of the daily variation of the mean coefficient of refraction deduced from our observations. The difference between the values of columns 3 and 5 is constant and equal to — 0.0008, and reduces the systematic series to values which would have been found had our observations suffered no break. It was found by first interpolating values for 7 a. m. for those days when observations were wanting at that hour by means of all other observations on each day and the known hourly variation of the refraction. The mean of 27 values was .0836, which, compared with .0844, gave the correction as stated. The next most complete hour is 6 a. m., for which the same result was obtained. Column 6 contains the hourly difference from the mean .0849.

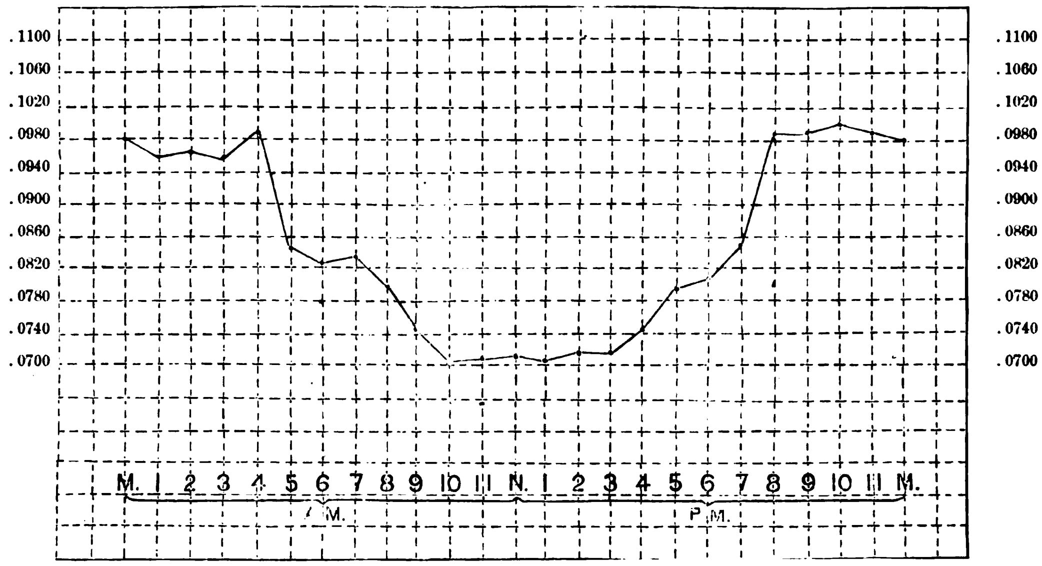
Hour.	Approximate series.	Systematic series.	*n*.	Final series of *m*.	Daily variation of coefficient.	Hour.	Approximate series.	Systematic series.	*n*.	Final series of *m*.	Daily variation of coefficient.
Midnight	.0983	.0988	5	.0980	+.0131	Noon ...	.0717	.0721	12	.0713	−.0136
1 a. m ...	.0964	.0970	5	.0962	+.0113	1 p. m..	.0712	.0717	12	.0709	−.0140
2 a. m ...	.0974	.0980	5	.0972	+.0123	2 p. m..	.0730	.0733	10	.0725	−.0124
3 a. m ...	.0961	.0967	5	.0959	+.0110	3 p. m..	.0726	.0730	10	.0722	−.0127
4 a. m ...	.0988	.0998	3	.0990	+.0141	4 p. m..	.0756	.0761	10	.0753	−.0096
5 a. m ...	.0894	.0854	5	.0846	−.0003	5 p. m..	.0801	.0807	10	.0799	−.0050
6 a. m....	.0823	.0836	19	.0828	−.0021	6 p. m..	.0849	.0818	12	.0810	−.0039
7 a. m ...	.0852	.0844	20	.0836	−.0013	7 p. m..	.0867	.0861	7	.0853	+.0004
8 a. m....	.0800	.0804	16	.0796	−.0053	8 p. m..	.1003	.0999	6	.0991	+.0142
9 a. m....	.0745	.0747	14	.0739	−.0110	9 p. m..	.1006	.0997	5	.0989	+.0140
10 a. m....	.0714	.0714	12	.0706	−.0143*	10 p. m..	.1016	.1007	5	.0999	+.0150†
11 a. m....	.0714	.0715	13	.0707	−.0142	11 p. m..	.1013	.1004	5	.0996	+.0147

* Minimum. † Maximum.

* The method is worked out and numerically illustrated in an application to certain long series of observations of temperature with a view of deducing a law of secular variation, in the "Smithsonian Contributions to Knowledge, No. 277. Tables, &c., of Atmospheric Temperature in the United States, &c., by C. A. Schott, Washington, March, 1875," p. 302.

Referring to the accompanying diagram, showing the final values of *m*, as observed at Ragged Mountain, it will be seen that we may note the following conclusions:

Daily variation of the coefficient of refraction, from observations at Ragged Mountain, Me., July, August, and September, 1874.



The daily variation of the atmospheric refraction is systematic; it is least in amount about 10 a. m. and greatest in amount about 10 p. m.; it is nearly constant and small from 9½ a. m. to 3 p. m., during which period of the day vertical angles for hypsometric purposes may be made with the greatest advantage, and whenever accuracy is desired they should be confined to this interval; it is nearly constant and large from 8 p. m to 4 a. m.; the night hours are therefore not suitable for observations of heights by vertical angles. Between 4 a. m. and 9½ a. m. the refraction is rapidly declining, as may be noticed by the gradual apparent sinking of distant objects toward and below the horizon; the reverse is the case between the hours from 3 p. m. to 8 p. m., when these objects gradually make their appearance. For questions as to intervisibility of distant objects, as for instance in reconnaissances for triangulations of the first order, the morning hour after twilight and the evening hour preceding it are those which the observer should select.

Comparing the results at Ragged Mountain, on the Atlantic, with those at Bodega Head and Ross Mountain, on the Pacific, we find them to run parallel, 10 a. m. being the hour of minimum refraction, but the low value continuing a little longer on the western coast stations, viz, from 9 a m. to 4 p. m. That *m* is found larger at Bodega Head and Ross Mountain than at Ragged Mountain is simply an accidental circumstance, existing during the five days of observation at the former stations.

To ascertain the effect of small errors in *h* the difference of level, in *s* the distance, and in ζ the observed zenith-distance, on the computed value of *m*, we make use of the formula—

$$h = s \cot \zeta + \frac{1-2m}{2\rho} s^2 + \frac{1-m}{\rho} s^2 \cot^2 \zeta + \ldots .$$

which by differentiation becomes—

$$dm = -\frac{\rho}{s^2}\, dh - \frac{\rho}{s^2}\left(\cot \zeta - \frac{2h}{s}\right) ds - \frac{\rho}{s \sin^2 \zeta}\, d\zeta$$

For the line Ragged to Mount Desert these coefficients become*

$$dm = -.00112\, dh + .000007\, ds - .00041\, d\zeta$$

* The last term has to be multiplied by arc 1″ since ζ is expressed in seconds.

If we suppose $dh = 0^{m}.1$, $ds = 1^{m}$ and $d\zeta = 2''$ we at once see the great accuracy with which the various values of m have been found. An error in ζ is the one most to be feared and for short lines the term $-\frac{\rho}{s \sin^2 \zeta} d\zeta$ becomes predominant; thus in the distance to Owl's Head Light, nearly 16 kilometers or about 10 statute miles, an error of but $1''$ in the observed zenith-distance produces an error of 0.0020 in the deduced coefficient of refraction; the values of m derived from this short line are not entitled to as much confidence as other values depending on longer lines.

To indicate, in general, the condition of the atmosphere, a table of meteorological observations, at noon, is herewith appended for each day on which the refractive power of the atmosphere was measured.

Meteorological observations, Ragged Mountain.

1874.	* m.	† Atmospheric pressure in inches.	Temperature of air. Fah.	‡ Diff. Dry − wet bulb. Fah.	Wind. Direction (true).	Wind. Force.	Clouds. Kind.	Clouds. Amount.	Appearance of sky.
			°	°					
July 22	(.086)	28.668	70.2	5.4	N. N. W.	1	Ci.-Cu.......	3	Hazy.
23	.088	.735	74.0	7.6	S. S. W.	1	....	0	Do.
27	.032	.622	65.4	2.0	S. W.	2	Cu	8	Do.
30	.025	.437	64.4	2.4	N. W.	2	Cu..........	4	Hazy a. m., clear p. m.
31	.081	.588	72.8	4.1	S. S. W.	1	Ci.-Cu.......	7	Hazy.
Aug. 3	(.053)	.451	58.4	5.2	N. W.	2	Cu..........	3	Clear.
4	.076	.659	58.2	1.4	N. W.	1	Cu	9	Do.
5	.076	.772	68.0	3.8	N.	2	Cu..........	5	Hazy.
6	(.066)	.659	64.3	3.2	N. W.	1	Cu..........	5	Slightly hazy.
19	(.086)	.815	64.5	5.6	N. W.	1	Ci.-St.... / Ci.-Cu....	3	Clear.
20	(.084)	.516	60.6	0.9	W. S. W.	2	....	....	Fog.
22	(.058)	.508	61.8	4.7	N. N. W.	1	Ci.-St.... / Ci.-Cu ...	4	Clear.
23	(.064)	.660	58.7	4.5	W.	1	Ci.-St.... / Cu.... ..	6	Do.
24	.053	.603	61.8	5.7	N. N. E.	1	Ci.-Cu.......	2	Do.
25	.075	.892	63.7	5.6	S. E.	1	Ci.-St.... / Cu.-St....	7	Very smoky.
26	(.084)	.923	65.2	6.1	E.	1	Ci.-Cu.......	3	Do.
27	(.085)	.868	68.0	7.1	S. S. E.	1	Ci.-Cu.... / Ci.-St....	6	Do.
28	(.096)	.788	71.8	6.4	E.	1	Ci. Cu.-St...	7	Smoky.
29	(.085)	.677	65.0	5.9	E. S. E.	1	Ci. Cu.-St...	8	Do.
Sept. 1	.069	.549	63.8	8.4	W. N. W.	2	Ci. Cu.-St...	5	Hazy.
2	.056	.604	62.8	4.8	N. N. W.	2	Ci. Cu.-St...	9	Slightly hazy.
3	(.078)	.503	68.9	5.7	W. S. W.	2	Ci	....	Very smoky.
5	(.093)	.964	62.9	3.6	S. W.	2	Ci. Ci.-St....	4	Do.
7	(.067)	.472	63.6	3.5	N. W.	2	Ci. Ci.-St ...	8	Smoky.
8	.070	.564	63.7	3.9	N. N. W.	1	Cu.........	6	Clear.
9	(.063)	.769	61.2	1.9	E.	1	Ci. Cu.-St ..	6	Hazy.
12	.073	.780	60.2	5.3	N.	1	Ci. Cu.-St...	3	Clear a. m., hazy p. m.
Mean..	.071	28.668	64.5	4.6	....	.. ..	....	....	

* Values between parentheses are interpolated from observations at other hours and known daily variation.
† Mercury at 32° Fahrenheit.
‡ Corrected for index-difference of the two thermometers.

It does not appear that any of these meteorological observations have any but a remote relationship to the observed amount of refraction; the rate of change of temperature with altitude on which the amount of refraction in a great measure depends, is not, in fact included, nor can the temperature of the intervening stratum of air be made, directly, a matter of observation. There is no marked feature in the meteorological record on July 27 and July 30, at which time the refraction was remarkably small, most probably due to a rapid diminution of temperature with height; it is noted that the clouds were low. It seems probable that the refraction is *smaller* with *westerly*

and *greater* than the average amount with *easterly* winds; this may be explained by a more equable distribution of temperature accompanying easterly winds, whereas during the prevalence of westerly winds the higher strata of the air are cooled more rapidly. In general, refraction is greater the greater the atmospheric pressure and the lower the atmospheric temperature.

The results of two short series of meteorological observations simultaneous with those taken at Ragged Mountain are appended; one at Mount Desert, the other at White Head Light. These observations refer to noon and the results are corrected for index-errors of instruments; the temperature of the mercury of the barometer is at 32° Fahrenheit.

Meteorological observations at Mount Desert.

1874.	*m.*	Atmospheric pressure.	Temp. Fah.	Dry−wet bulb.	Wind. Direction.	Wind. Force.	Clouds. Kind.	Clouds. Amount.	Appearance of sky.
		Inches.	°	°					
Aug. 23	(.064)	28.412	58.1	5.5	W.S.W.	1	St	9	Clear.
24	.053	.338	59.7	7.7	W.	1	Cu..... ..	3	Hazy.
25	.075	.634	58.8	7.4	N. E.	1	....	9	Fog, hazy.
26	(.084)	.666	59.9	5.3	N. E.	1	Cu.......	3	Very hazy.
27	(.085)	.609	62.4	5.7	E.	1	Ci.-cu ...	10	Do.
28	(.096)	.543	64.9	7.3	N. E.	1	Ci	8	Do.
29	(.085)	.428	63.6	4.4	E. S. E.	1	Ci.-st., cu	10	Do.
Sept. 1	.069	.252	62.5	9.2	W.	2	Ci.-cu....	9	Clear.

Meteorological observations at White Head Light.

1874.	*m.*	Atmospheric pressure.	Temp. Fah.	Dry−wet bulb.	Wind. Direction.	Wind. Force.	Clouds. Kind.	Clouds. Amount.	Appearance of sky.
Sept. 7	(.067)	29.752	69.0	7.1	N.	1	Ci.-cu	7	Clear.
8	.070	29.859	64.1	4.0	W.	1	Cu.-st ...	9	Do.
9	.063	30.088	60.7	2.4	S.	1	Cu........	3	Do.
12	.073	30.112	56.0	3.8	N. E.	1	Ci.-cu ...	3	Do.

C.—Meteorological observations at Ragged Mountain, at Mount Desert, and at White Head Light; two short simultaneous sets.

In connection with the investigation of the refraction the party of Subassistant Perkins secured two short series of hourly simultaneous meteorological observations, one at Ragged Mountain and White Head Light, and the other at Ragged Mountain and Mount Desert, which, in part, have already been referred to above. From these series I propose to present briefly the hypsometric results depending on the observed heights of the barometric columns. It should be remarked, however, that the daily meteorological observations at Ragged Mountain extend over the whole time the station was occupied—that is, from July 22 to September 18, 1874.

Barometer Green No. 2049 was used at Ragged Mountain, and barometer Green No. 1937 at White Head Light and at Mount Desert; they are mercurial instruments, and to the latter a differential index-correction of +0.015 inch has been applied to make its indications comparable with those of No. 2049; the heights of the mercurial columns are reduced to the temperature of 32° Fah. The readings of the thermometers are corrected for small errors of graduation. The tabular numbers for August 26, 6 a. m., at Ragged Mountain, are interpolations.

The mean values from eight days' observations show a pressure maximum between 9 and 10 a. m. and a pressure minimum about 4 p. m. The temperature of the air as well as the difference between the readings and the dry and wet bulbs is greatest between the hours 1 and 3 p. m.

The hourly values for differences of height are computed by Dr. Rühlmann's formula, and they are compared with the true difference of height as determined by means of the spirit-level, viz:

Surface of cistern of mercury of barometer at Ragged Mountain *above* that of barometer at White Head Light 375.261 meters, and surface of mercury at Ragged Mountain *below* that at Mount Desert 74.626 meters.

Ragged Mountain and White Head Light.

BAROMETRIC PRESSURE.

Hour.	Station. 1874.	Sept. 7.	Sept. 8.	Sept. 9.	Sept. 10.	Sept. 11.	Sept. 12.	Sept. 14.	Sept. 15.	Mean pressure at R. Mtn.	Mean pressure at W. H. Lt.
		28 inches +									
		Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
6 a. m..	Ragged Mtn ...	.511	.536	.746	.544	.535	.734	.900	.818	28.666	
	White Head Lt.	.804	.849	1.062	.864	.842	1.083	1.248	1.155		29.988
7 a. m..	Ragged Mtn ...	.496	.551	.749	.539	.516	.754	.906	.823	.667	
	White Head Lt.	.798	.856	1.075	.854	.821	1.093	1.252	1.157		.988
8 a. m..	Ragged Mtn ..	.498	.550	.764	.529	.525	.770	.906	.825	.671	
	White Head Lt.	.794	.871	1.086	.822	.849	1.105	1.257	1.157		.993
9 a. m..	Ragged Mtn ..	.495	.560	.772	.533	.538	.774	.914	.824	.676	
	White Head Lt.	.795	.874	1.108	.823	.839	1.113	1.262	1.159		.997
10 a. m..	Ragged Mtn ...	.493	.552	.779	.531	.541	.784	.921	.820	.678	
	White Head Lt.	.783	.862	1.096	.810	.838	1.118	1.263	1.152		.990
11 a. m..	Ragged Mtn ...	.464	.564	.770	.526	.512	.781	.909	.817	.668	
	White Head Lt.	.760	.859	1.095	.806	.820	1.113	1.245	1.150		.981
Noon..	Ragged Mtn ...	.472	.564	.769	.502	.527	.780	.907	.816	.667	
	White Head Lt.	.752	.860	1.088	.779	.815	1.112	1.253	1.139		.975
1 p. m..	Ragged Mtn ..	.475	.573	.754	.473	.525	.787	.909	.806	.663	
	White Head Lt.	.756	.866	1.081	.756	.814	1.110	1.242	1.127		.969
2 p. m..	Ragged Mtn ..	.472	.569	.750	.453	.513	.788	.896	.797	.655	
	White Head Lt.	.763	.856	1.069	.727	.806	1.112	1.237	1.110		.960
3 p. m..	Ragged Mtn ..	.467	.562	.738	.449	.522	.790	.898	.769	.649	
	White Head Lt.	.769	.861	1.074	.706	.805	1.114	1.227	1.080		.955
4 p. m..	Ragged Mtn ..	.468	.577	.725	.448	.532	.795	.880	.766	.649	
	White Head Lt.	.771	.866	1.039	.698	.817	1.115	1.215	1.076		.950
5 p. m..	Ragged Mtn ...	.472	.595	.714	.463	.548	.810	.868	.761	.654	
	White Head Lt.	.781	.899	1.034	.718	.836	1.126	1.202	1.071		.958
6 p. m..	Ragged Mtn ..	.496	.607	.718	.472	.575	.823	.865	.749	.663	
	White Head Lt.	.801	.913	1.028	.745	.863	1.141	1.199	1.058		.969

TEMPERATURE OF THE AIR AND DIFFERENCE OF DRY AND WET BULB THERMOMETERS.

Hour.	Station.	Sept. 7.		Sept. 8.		Sept. 9.		Sept. 10.		Sept. 11.		Sept. 12.		Sept. 14.		Sept. 15.		Mean.	
		° F.		° F.		° F.		° F.		° F.		° F.		° F.		° F.		° F.	° F.
6 a. m..	Ragged Mtn ...	57.6	2.5	53.5	2.1	53.0	0.9	56.0	1.4	57.0	6.8	47.0	3.2	51.6	0.9	55.7	0.6	53.9	2.3
	White Head Lt.	57.6	1.6	55.7	1.8	55.7	1.5	56.9	0.8	59.1	3.2	50.7	3.4	55.4	0.8	56.3	0.5	55.9	1.7
7 a. m..	Ragged Mtn .	57.5	2.5	53.9	1.9	53.6	0.8	58.3	2.8	56.4	6.8	48.8	3.4	52.0	1.1	55.8	0.7	54.5	2.5
	White Head Lt.	59.7	1.4	57.6	1.7	56.4	1.5	57.0	0.9	58.8	3.3	52.5	3.6	56.4	0.9	56.9	1.4	56.9	1.8
8 a. m..	Ragged Mtn ..	58.2	2.7	54.6	1.9	54.3	0.8	60.8	3.4	56.0	5.7	51.7	3.7	53.6	0.9	56.0	0.5	55.6	2.5
	White Head Lt.	61.8	2.2	59.9	3.2	57.4	1.7	59.1	1.4	58.9	4.2	54.8	4.9	58.1	1.5	57.4	0.6	58.4	2.5
9 a. m..	Ragged Mtn ..	59.6	2.9	55.6	1.9	56.3	0.9	63.0	3.9	58.5	6.1	55.0	4.0	56.0	1.2	56.2	0.7	57.5	2.7
	White Head Lt.	64.1	3.7	61.9	4.2	58.0	1.8	61.1	3.0	63.4	5.1	54.8	4.8	58.5	1.5	58.4	1.0	60.0	3.1
10 a. m..	Ragged Mtn ..	61.6	2.9	57.8	1.9	58.5	0.9	66.2	3.5	61.0	9.6	57.2	4.3	58.0	1.4	56.6	0.6	59.6	3.1
	White Head Lt.	67.1	6.0	64.9	5.2	59.3	1.8	61.7	2.4	67.4	11.3	54.9	4.2	59.0	1.7	58.8	1.1	61.6	4.2
11 a. m..	Ragged Mtn ...	62.4	3.5	61.8	3.0	61.5	2.2	69.0	3.7	62.5	11.4	59.0	4.8	60.0	1.9	57.0	0.5	61.6	3.9
	White Head Lt.	69.4	6.5	66.2	6.2	60.5	2.3	62.8	2.8	70.7	12.2	55.2	3.9	59.7	2.0	59.9	1.4	63.0	4.7
Noon ..	Ragged Mtn .	63.6	3.5	63.7	3.9	61.2	1.9	72.0	3.4	64.4	10.5	60.2	5.3	61.2	2.4	57.5	0.4	63.0	3.9
	White Head Lt.	69.0	7.1	64.1	4.0	60.7	2.4	61.7	2.8	72.1	14.5	56.0	3.8	61.1	2.3	59.9	1.6	63.1	4.8
1 p. m..	Ragged Mtn ..	63.4	4.5	64.3	4.1	63.4	2.0	74.0	4.9	66.4	11.0	61.7	5.6	62.0	2.4	58.8	0.9	64.3	4.2
	White Head Lt.	68.8	6.8	62.8	3.4	61.4	2.6	62.3	2.9	73.2	17.0	56.8	4.5	60.4	2.1	59.5	1.4	63.2	5.1
2 p. m..	Ragged Mtn ...	62.4	4.2	65.9	2.9	63.7	1.8	75.2	7.0	68.2	12.7	62.0	4.7	62.2	2.8	59.7	1.4	64.9	4.7
	White Head Lt.	68.7	7.3	61.7	3.1	59.5	2.3	63.0	3.0	73.2	15.7	57.7	5.0	59.6	2.0	59.6	1.2	62.9	5.0
3 p. m..	Ragged Mtn ..	61.9	3.7	66.8	4.0	64.0	1.9	77.0	8.7	69.8	11.7	62.0	5.6	61.8	2.5	60.0	1.1	65.4	4.9
	White Head Lt.	66.1	5.6	62.2	3.1	58.4	2.0	64.7	3.0	73.9	15.8	59.0	5.3	59.1	1.8	59.2	1.3	62.8	4.7
4 p. m..	Ragged Mtn ..	61.7	3.9	62.8	1.5	62.9	2.0	76.8	12.8	68.9	9.7	61.5	5.1	59.5	2.1	59.2	1.4	64.2	4.8
	White Head Lt.	67.0	6.8	62.2	2.8	57.7	0.7	64.4	2.9	66.7	11.3	60.1	5.3	58.6	1.9	58.9	1.3	62.0	4.1
5 p. m..	Ragged Mtn ...	61.2	3.9	61.8	2.3	61.4	2.0	74.0	10.6	66.6	8.9	60.5	3.2	58.0	1.9	58.5	0.9	62.8	4.2
	White Head Lt.	66.0	6.5	62.6	2.8	56.4	1.7	74.4	6.2	61.2	5.5	56.4	2.9	57.7	1.7	57.4	0.8	61.5	3.5
6 p. m..	Ragged Mtn ...	60.3	3.5	60.8	2.5	58.5	2.1	71.2	9.8	61.8	8.7	58.0	3.7	55.5	1.7	58.0	0.9	60.5	4.1
	White Head Lt.	63.4	5.1	62.3	2.7	55.4	1.0	73.1	9.4	59.8	2.2	57.3	0.8	57.1	1.4	56.7	0.5	60.6	2.9

Ragged Mountain and Mount Desert.

BAROMETRIC PRESSURE.

Hour.	Station. 1874.	Aug. 24.	Aug. 25.	Aug. 26.	Aug. 27.	Aug. 28.	Aug. 29.	Aug. 31.	Sept. 1.	Mean pressure at Ragged Mountain.	Mean pressure at Mount Desert.
		28 inches +									
		Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
6 a. m.	Ragged Mtn	.586	.824	.910	.891	.804	.684	.584	.599	28.735	
	Mount Desert	.319	.574	.662	.631	.545	.435	.334	.302		28.475
7 a. m.	Ragged Mtn	.593	.840	.930	.896	.800	.685	.587	.598	.741	
	Mount Desert	.319	.591	.672	.640	.543	.432	.337	.303		.480
8 a. m.	Ragged Mtn	.595	.850	.931	.893	.794	.686	.599	.580	.741	
	Mount Desert	.325	.601	.682	.639	.545	.445	.346	.281		.483
9 a. m.	Ragged Mtn	.606	.864	.942	.894	.810	.693	.603	.582	.749	
	Mount Desert	.327	.617	.695	.646	.557	.434	.357	.289		.490
10 a. m.	Ragged Mtn	.600	.886	.943	.887	.803	.692	.604	.585	.750	
	Mount Desert	.329	.631	.690	.638	.550	.438	.358	.275		.489
11 a. m.	Ragged Mtn	.604	.893	.942	.875	.803	.682	.603	.554	.745	
	Mount Desert	.328	.633	.671	.616	.557	.420	.360	.262		.481
Noon	Ragged Mtn	.603	.892	.923	.868	.788	.677	.594	.549	.737	
	Mount Desert	.338	.634	.666	.609	.543	.428	.354	.252		.478
1 p. m.	Ragged Mtn	.606	.892	.919	.846	.792	.667	.590	.530	.730	
	Mount Desert	.337	.633	.650	.597	.529	.418	.344	.241		.469
2 p. m.	Ragged Mtn	.609	.885	.900	.839	.777	.653	.585	.500	.719	
	Mount Desert	.342	.638	.641	.586	.527	.397	.332	.223		.461
3 p. m.	Ragged Mtn	.621	.876	.892	.833	.771	.632	.579	.511	.714	
	Mount Desert	.350	.633	.634	.577	.508	.393	.325	.223		.455
4 p. m.	Ragged Mtn	.633	.877	.879	.819	.759	.641	.574	.502	.710	
	Mount Desert	.370	.629	.625	.570	.512	.386	.318	.242		.456
5 p. m.	Ragged Mtn	.647	.880	.886	.815	.748	.636	.574	.512	.712	
	Mount Desert	.373	.624	.625	.561	.504	.391	.315	.237		.454
6 p. m.	Ragged Mtn	.659	.878	.880	.820	.749	.648	.568	.529	.716	
	Mount Desert	.391	.620	.626	.565	.497	.420	.317	.253		.461

TEMPERATURE OF THE AIR AND DIFFERENCE OF DRY AND WET BULB THERMOMETERS.

Hour.	Station.	Aug. 24.		Aug. 25.		Aug. 26.		Aug. 27.		Aug. 28.		Aug. 29.		Aug. 31.		Sept. 1.		Mean.	
		° F.		° F.		° F.		° F.		° F.		° F.		° F.		° F.		° F.	° F.
6 a. m.	Ragged Mtn	50.4	2.3	51.5	3.8	51.0	4.1	54.8	4.2	57.8	4.7	61.0	3.3	60.6	3.9	53.2	3.9	55.0	3.8
	Mount Desert	50.8	1.8	54.6	6.1	52.8	5.3	55.8	5.9	59.8	7.2	61.6	6.6	62.3	4.4	51.5	2.2	56.1	4.9
7 a. m.	Ragged Mtn	51.0	2.7	54.0	3.9	54.4	3.5	55.0	3.4	59.6	5.0	61.2	3.6	61.8	4.8	53.6	3.8	56.3	3.8
	Mount Desert	52.3	3.8	55.8	7.0	55.8	5.7	56.0	5.7	59.1	6.4	60.1	5.7	66.4	5.8	55.0	3.7	57.6	5.5
8 a. m.	Ragged Mtn	53.7	3.4	57.4	4.8	57.6	4.7	59.0	4.9	65.0	5.9	63.4	3.2	64.5	5.0	56.0	3.9	59.6	4.5
	Mount Desert	53.1	4.4	58.0	8.3	58.8	6.1	58.1	5.5	60.1	6.2	63.7	7.5	69.9	7.2	57.5	5.0	59.9	6.3
9 a. m.	Ragged Mtn	56.4	3.6	60.0	4.5	59.2	4.6	63.7	5.5	67.0	6.5	64.4	5.1	66.4	5.8	58.0	5.0	61.9	5.1
	Mount Desert	54.8	5.2	58.8	7.9	60.5	6.1	60.4	6.6	61.5	6.7	61.9	4.4	72.9	7.7	59.5	6.2	61.3	6.4
10 a. m.	Ragged Mtn	59.0	4.1	62.0	5.7	61.7	5.1	66.2	5.3	69.6	6.1	64.5	5.9	68.2	5.4	60.0	5.3	63.9	5.4
	Mount Desert	56.4	5.8	58.2	5.3	60.4	5.4	61.5	6.9	62.0	6.5	64.0	5.9	72.2	7.1	59.3	4.5	61.8	5.9
11 a. m.	Ragged Mtn	61.0	4.9	62.4	5.9	63.6	5.2	67.2	5.9	71.4	6.7	66.0	6.0	70.0	5.2	62.0	6.1	65.4	5.7
	Mount Desert	58.4	6.0	57.8	6.4	58.8	4.8	60.2	6.2	58.6	7.0	60.1	5.5	72.3	6.1	61.2	8.1	60.9	6.3
Noon	Ragged Mtn	61.8	5.7	63.7	5.6	65.2	6.1	68.0	7.1	71.8	6.9	65.0	5.9	71.5	5.7	63.8	8.4	66.3	6.4
	Mount Desert	59.7	7.7	58.8	7.4	59.9	5.3	62.4	5.7	64.9	7.3	63.6	4.4	72.2	6.7	62.5	9.2	63.0	6.7
1 p. m.	Ragged Mtn	63.2	5.5	64.0	6.1	64.8	5.9	68.0	7.2	71.0	6.4	66.5	5.5	73.0	6.5	64.0	8.7	66.8	6.5
	Mount Desert	59.8	7.2	59.9	7.7	61.7	5.8	63.5	6.9	61.9	7.2	64.9	4.4	73.0	6.8	62.5	8.9	63.4	6.9
2 p. m.	Ragged Mtn	64.9	6.7	64.5	6.2	66.0	6.5	67.8	6.6	71.2	6.7	66.4	5.7	74.4	6.7	64.0	8.3	67.4	6.7
	Mount Desert	61.3	8.4	61.4	6.9	61.2	5.7	60.7	6.9	67.4	7.3	62.3	3.8	72.4	7.2	59.7	7.5	63.3	6.7
3 p. m.	Ragged Mtn	63.8	6.2	64.0	5.9	65.5	6.7	67.3	6.7	70.8	6.7	64.4	4.7	74.5	6.9	65.2	8.9	66.9	6.6
	Mount Desert	62.7	7.7	59.4	6.1	59.1	5.3	61.0	7.4	66.0	6.6	62.3	4.9	71.0	6.3	58.7	8.2	62.5	6.6
4 p. m.	Ragged Mtn	63.8	5.9	63.2	5.8	64.7	6.0	65.8	5.7	69.6	6.1	63.6	4.9	72.8	6.8	65.2	8.7	66.1	6.2
	Mount Desert	61.5	8.0	56.3	6.5	58.8	5.6	62.8	7.2	67.1	7.0	58.5	2.9	68.4	5.0	55.4	6.0	61.1	6.0
5 p. m.	Ragged Mtn	62.0	4.9	60.8	5.4	63.0	5.5	62.6	5.9	67.8	5.8	63.2	4.6	71.5	6.6	63.7	7.5	64.3	5.8
	Mount Desert	60.4	8.0	54.9	7.1	59.4	5.3	59.9	8.5	66.7	6.1	57.8	1.4	65.2	4.6	54.3	5.4	59.8	5.7
6 p. m.	Ragged Mtn	59.8	4.8	58.8	4.5	61.8	6.9	58.8	5.7	65.2	6.3	58.8	3.0	68.8	6.3	61.8	6.7	61.7	5.5
	Mount Desert	58.0	5.7	55.2	4.5	59.0	4.5	59.1	6.8	64.4	3.8	56.5	1.8	64.4	4.2	52.9	4.1	58.7	4.4

Resulting differences of height.

Hour.	Ragged Mountain – White Head Light.	Excess over true *h*.	Mean observed temperature at stations.	Computed temperature.	Apparent correction to temperature.	Apparent correction for coast of California.	Mount Desert – Ragged Mountain.	Excess over true *h*.
	m.	*m.*	° F.	° F.	° F.	° F.	*m.*	*m.*
6 a. m	379. 59	4. 33	54. 9	49. 0	– 5. 9	....	76. 57	1. 95
7 a. m	379. 94	4. 68	55. 7	49. 4	– 6. 3	0. 0	77. 09	2. 46
8 a. m	381. 15	5. 89	57. 0	49. 0	– 8. 0	–2. 0	76. 62	2. 00
9 a. m ...	382. 24	6. 98	58. 7	49. 3	– 9. 4	–5. 8	77. 21	2. 59
10 a. m	381. 06	5. 80	60. 6	52. 7	– 7. 9	–7. 4	78. 01	3. 39
11 a. m	382. 76	7. 50	62. 3	52. 0	–10. 3	–8. 5	78. 96	4. 34
Noon . ..	381. 94	6. 68	63. 0	54. 0	– 9. 0	–8. 8	77. 69	3. 07
1 p. m	381. 95	6. 69	63. 7	54. 6	– 9. 1	–9. 9	78. 42	3. 79
2 p. m	381. 90	6. 64	63. 9	54. 9	– 9. 0	–9. 2	77. 57	2. 94
3 p. m	382. 42	7. 16	64. 1	54. 3	– 9. 8	–8. 6	77. 78	3. 15
4 p. m	380. 19	4. 93	63. 1	56. 3	– 6. 8	–7. 5	76. 11	1. 49
5 p. m	380. 34	5. 08	62. 1	55. 2	– 6. 9	–4. 8	77. 07	2. 45
6 p. m ..	379. 53	4. 27	60. 5	54. 8	– 5. 7	....	75. 89	1. 27

The results by Rühlmann's formula are intermediate between those by Loomis' formula and by Plantamour's formula. Thus for 11 a. m. we have, by L., 381^{m}.57; by R., 382^{m}.76; and by P., 383^{m}.50. The differences of height, as deduced from the barometric observations during the day, are as usual too great, and if we compute the temperature of the intervening stratum of air from these observations, and the known difference of height by spirit-level, we find the above apparent temperature-corrections. These compare fairly, in extreme magnitude, with similar corrections deduced from the observations at Bodega Head and Ross Mountain, in California; yet the fact that all the computed heights, even those at the earliest hour, are too great, is, perhaps, to be explained by the influx of cold air in the Penobscot Valley. It will be noticed that the observations at Ragged Mountain and White Head Light still leave to the intervening stratum of air a daily variation, not very much smaller in amount than the daily variation recorded at the two stations; whereas the observations on the coast of California left that stratum in a state of uniform temperature throughout the day. The explanation of this difference is no doubt to be sought for in local causes. The fact that on the coast of Maine hourly observations, commenced at 6 a. m., do not include the true difference of height, may be regarded as unexpected as the uniform temperature of the intervening mass of the air deduced from the California observations.

The observations at Ragged Mountain and Mount Desert cannot be made to yield a reliable result for the temperature of the air between these stations, owing to their great distance and small difference of height; yet they point unmistakably to the fact that, with air in motion and for such distance, the surface of strata of equal density cannot be concentric with the equilibrium surface of the ocean.

It is evident that further observations are desirable, and that barometric hypsometry cannot be made the basis of exact determinations of heights.

Respectfully submitted by

CHAS. A. SCHOTT,
Assistant.

APPENDIX No. 18.

ON ATMOSPHERIC REFRACTION AND ADJUSTMENT OF HYPSOMETRIC MEASURES—CONTRIBUTION No. III.

DETERMINATION OF THE COEFFICIENT OF REFRACTION FROM ZENITH-DISTANCES OBSERVED IN NORTHERN GEORGIA, BY ASSISTANTS C. O. BOUTELLE AND F. P. WEBBER, IN 1873 AND 1874, AND ADJUSTMENT OF DIFFERENCES OF HEIGHTS BY APPLICATION OF THE METHOD OF LEAST SQUARES. DISCUSSION AND REPORT BY CHARLES A. SCHOTT, ASSISTANT.

MAY 13, 1876.

The measures for refraction and heights of stations discussed in this paper are those taken in connection with that part of the primary triangulation which traverses Northern Georgia; these observations will therefore enable us to exhibit the amount of variability in the atmospheric refraction, and its effect on the measures of heights as ordinarily met with at a considerable distance from the sea coast and at altitudes between 1000 and 2300 feet, and may thus be contrasted with the results obtained at stations near the coast, as at Bodega Head, California, and at Ragged Mountain, Me. (see Appendices Nos. 16 and 17, of this report), where the observations were principally directed to the study of the law of *daily variation* in the refraction. The present paper is therefore to some extent supplementary to those communications, inasmuch as it presents results of refraction obtained under different conditions; the second part contains the method of reduction of hypsometric measures applicable to the case under consideration, with remarks for modification to suit other circumstances, the small errors existing among the separate measures being dispersed by the use of the method of least squares. Numerical examples are introduced for illustration, no communication having been made on this subject heretofore.

1.—RESULTS OF ATMOSPHERIC REFRACTION OBSERVED AT STATIONS IN NORTHERN GEORGIA IN 1873 AND 1874.

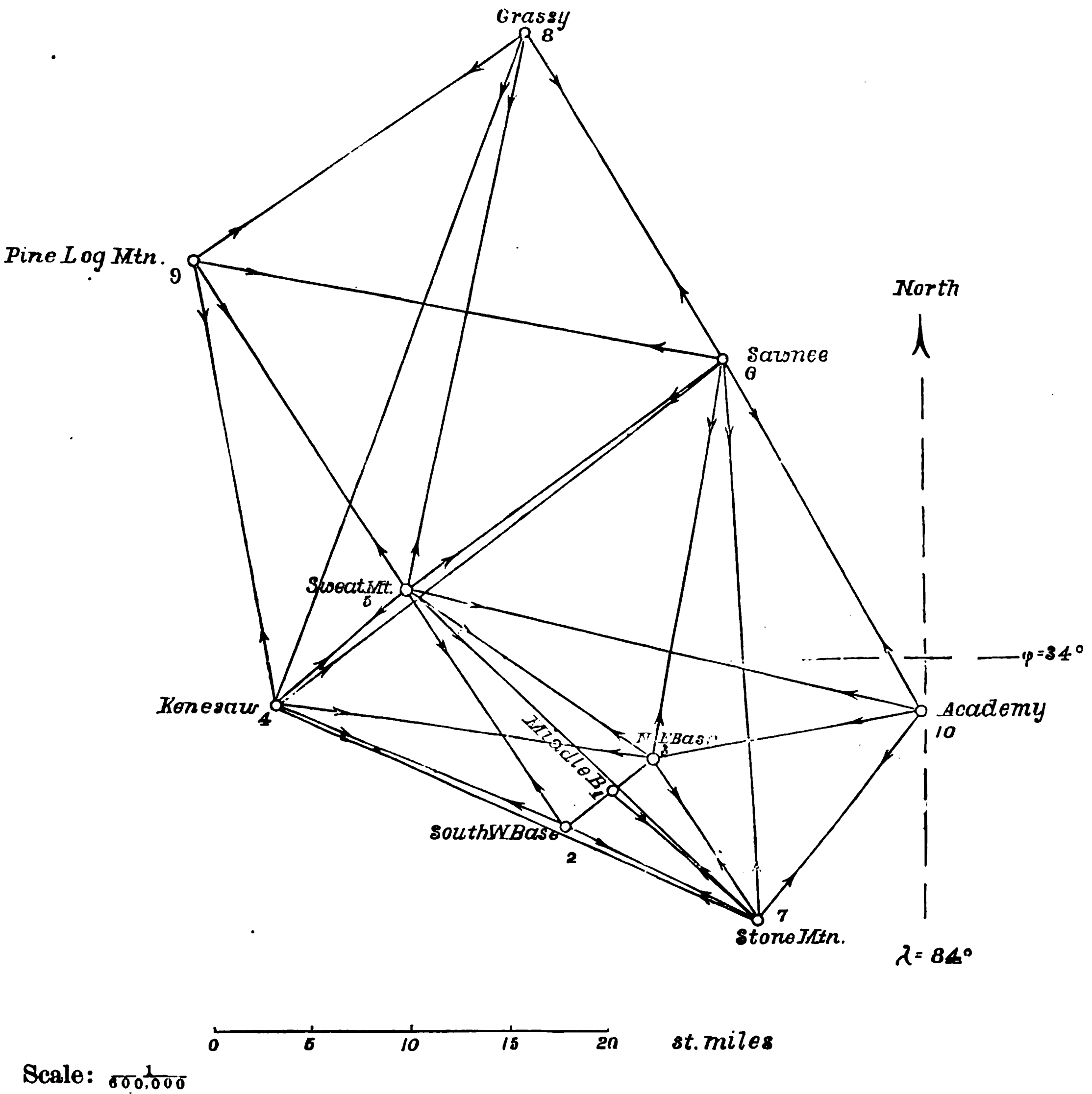
That part of the primary triangulation along the southeastern flank of the Appalachian system of mountains, which crosses Northern Georgia and which comprises the stations "Southwest, Middle, and Northeast Base (see Appendix No. 12, Coast Survey Report for 1873), Stone Mountain, Academy, Sweat, Kenesaw, Sawnee, Pine Log, and Grassy," was executed in the years 1873 and 1874, by the parties of Assistants C. O. Boutelle and F. P. Webber. The vertical measures are those ordinarily taken at primary stations for the determination of heights and comprise double-zenith distances as well as differential micrometric measures. One turn of the eye-piece or Ramsden micrometer of the 30-*inch theodolite*, C. S. No. 1, was found to be as follows:

At Northeast Base, 1873.....	$= 43''.270 \pm 0''.075$	
At Kenesaw, 1873	$43''.523 \pm 0''.054$	Mean, $43''.362 \pm 0''.034$
At Sweat, 1873	$43''.293 \pm 0''.042$	

One turn of the eye-piece micrometer of the 20-*inch theodolite*, C. S. No. 3, was found—

At Sawnee, 1873	$= 52''.629 \pm 0''.083$	
At Grassy, 1874	$52''.454 \pm 0''.104$	Mean, $52''.536 \pm 0''.046$
At Skitt, 1874	$52''.525 \pm 0''.040$	

Part of triangulation in Georgia.—Measures of zenith-distances.



Scale: $\frac{1}{600,000}$

N. B.—The arrows indicate measured zenith-distances; the lines 1..2 and 1..3 were leveled, hence the measured zenith-distances are not indicated.

The vertical measures were generally taken between 10 a. m. and 4 p. m., or during that part of the day when the refraction is least and most steady, and extended only occasionally to 5 p. m. or even later. All measures were referred by the computer to the ground; that is, they were corrected for height above ground of instrument and of object observed on. If any conditions existed between the zenith-distances as directly observed and the micrometric differences of zenith-distances the small discrepancies were dispersed by application of the method of least squares. The resulting zenith-distances tabulated below are those referring to our proposed geometrical nexus of stations, all others having been omitted here.

Southwest Base.

C. O. Boutelle, 1873. Micr. diff. February 17, 19, 21. Theod. No. 1. Zen. dist. March 7, 14. Vert. Cir. No. 24.

		°	′	″
Middle Base	ζ =	89	55	41.1
Northeast Base		89	59	20.3
Sweat		89	37	53.7
Kenesaw		89	36	10.1
Stone		89	26	21.6

Middle Base.

C. O. Boutelle, 1873. Micr. diff. February 3, 5. Theod. No. 1. Zen. dist. February 12. Vert. Cir. No. 32.

		°	′	″
Southwest Base	ζ =	90	06	34.2
Northeast Base		90	00	38.5
Stone		89	24	30.6

Northeast Base.

C. O. Boutelle, 1873. Micr. diff. March 18, 20, 21. Theod. No. 1. Zen. dist. March 23. Vert. Cir. No. 24.

		°	′	″
Middle Base	ζ =	90	01	43.0
Southwest Base		90	05	09.4
Kenesaw		89	43	22.7
Sweat		89	39	51.7
Sawnee		89	40	31.2
Stone		89	24	04.0

Stone Mountain.

C. O. Boutelle, 1873. Micr. diff. December 19, 20. Theod. No. 3. Zen. dist. December 18, 19. Vert. Cir. No. 24.

		°	′	″
Middle Base	ζ =	90	43	30.0
Northeast Base		90	43	20.8
Southwest Base		90	41	56.8
Academy		90	30	55.7
Sweat		90	08	58.9
Kenesaw		90	07	05.0
Sawnee		90	04	43.1

Sweat Mountain.

F. P. Webber, 1873. Micr. diff. September 30, October 1, 2, 3. Theod. No. 1. Zen. dist. October 4. Vert. Cir. No. 32.

		°	′	″
Southwest Base	ζ =	90	33	37.2
Northeast Base		90	31	43.4
Academy		90	23	21.4
Stone		90	09	37.0
Sawnee		89	58	49.3
Kenesaw		89	55	32.5
Pine Log		89	46	58.9
Grassy		89	36	07.9

Kenesaw.

F. P. Webber, 1873. Micr. diff. July 21, 22, 25, 29, 30, August 2, 4, 7, 8. Theod. No. 1. Zen. dist. August 16. Vert. Cir. No. 32.

		°	′	″
Southwest Base	ζ =	90	36	15.2
Northeast Base		90	31	28.4
Stone		90	13	03.4
Sweat		90	11	28.0
Sawnee		90	07	44.6
Pine Log		89	54	41.7

Sawnee.

C. O. Boutelle, 1873. Micr. diff. October 31, November 3, 7, 11, 8, 10, December 4. Theod. No. 1. Zen. dist. November 7, 8. Vert. Cir. No. 24.

		°	′	″
Northeast Base	ζ =	90	35	16.5
Academy		90	33	05.9
Stone		90	17	08.2
Sweat		90	16	14.4
Kenesaw		90	14	20.3
Pine Log		90	01	43.9
Grassy		89	23	48.8

Academy.

C. O. Boutelle, 1874. Micr. diff. December 7, 8, 9, 10. Theod. No. 3. Zen. dist. December 9, 10. Vert. Cir. No. 24.

		°	′	″
Northeast Base	ζ =	90	08	11.4
Sweat		89	57	09.3
Sawnee		89	42	51.5
Stone		89	39	00.1

Pine Log.

F. P. Webber, 1874. Zen. dist. August 3, 4, 5. Vert. Cir. No. 32.

		°	′	″
Sweat	ζ =	90	28	20.0
Kenesaw		90	23	23.4
Sawnee		90	19	09.5
Grassy		89	38	05.3

Grassy.

C. O. Boutelle, 1874. Micr. diff. July 21, 23, 28, 31. Theod. No. 3. Zen. dist. July 31, August 1. Vert. Cir. No. 24.

		°	′	″
Sawnee	ζ =	90	50	53.9
Sweat		90	45	59.0
Kenesaw		90	39	35.9
Pine Log		90	37	29.3

N. B.—Instrument No. 24 has a vertical circle of 8 inches; instrument No. 32 one of 12 inches, both by Gambey.

DETERMINATION OF THE COEFFICIENT OF ATMOSPHERIC REFRACTION FROM OBSERVED ZENITH-DISTANCES.

To determine the coefficient of refraction (m) from observations at two intervisible stations, we require either the measure of one zenith-distance (ζ) combined with the known difference of height as found by spirit-level, or the measure of reciprocal zenith-distances, which may be synchronous or not. In the first case we have the most favorable condition for finding the value of m, and if simultaneous observations are made at both ends of the line additional information is obtained respecting the difference of refraction and curvature of ray of light. In the second case we have to assume the refraction the *same* at both stations, and, in general, the path of light to form a part of an arc of a circle; in the third case of non-simultaneous observations we can only find an average value of m obtaining at the times when the two measures were made. It should also be remarked that the observed zenith-distances should be corrected for local deflection of the plumb-line in the direction of the azimuth of the line whenever we possess the means of doing it.* In the case before us the measures ζ and ζ' are reciprocal and, as the dates indicate, not synchronous, and the average values of m will only be approximate ones since the assumption in the following formula of the pencil of light as part of a circle is not in conformity with the law of change of density of the air with height. Supposing ζ and ζ' reduced to the ground (for height of telescope and of object sighted) $s =$ the horizontal distance between the two stations, ρ the radius of curvature† corresponding to this line, then

$$m = 0.5 - \frac{\zeta + \zeta' - 180^\circ}{2\,\psi} \qquad \text{where } \psi = \frac{s}{\rho \sin 1''}.$$

Respecting weights on account of number of observations, we may assume with Bessel $w = \dfrac{nn'\sqrt{s}}{n+n'}$ where $n =$ the number of measures of ζ and n' those of ζ'. For the present application it is preferred to let $n\,n'$ represent the number of days on which zenith-distances were observed instead of the number of individual observations, since the refraction generally varies more from day to day than on the same day between the hours 10 a. m. and 3 p. m., to which interval the observations of zenith-distances should be confined. No attempt has been made to correct observed zenith-distances for daily variation,‡ the refraction being sufficiently constant for times within about three hours from noon. The two measures for m over the very short lines from Middle Base to each end of the base are here excluded.

Resulting values for coefficient of refraction.

Line.	m	w	Line.	m	w
Middle Base — Stone	0.0480	85	Southwest Base — Kenesaw	0.0662	109
Southwest Base — Stone	660	133	Stone — Kenesaw	781	140
Southwest Base — Northeast Base	538	65	Stone — Sawnee	771	219
Northeast Base — Stone	795	85	Sawnee — Northeast Base	758	123
Sweat — Stone	768	135	Sawnee — Academy	722	186
Sweat — Northeast Base	738	80	Sawnee — Kenesaw	754	146
Sweat — Southwest Base	626	104	Sawnee — Sweat	780	121
Stone — Academy	858	149	Sawnee — Pine Log	675	254
Sweat — Academy	727	141	Pine Log — Kenesaw	679	148
Sweat — Pine Log	680	136	Grassy — Sweat	730	146
Sweat — Kenesaw	729	62	Grassy — Sawnee	722	178
Northeast Base — Kenesaw	705	90	Grassy — Pine Log	690	220

$$\text{Weighted mean } \frac{\Sigma\, m\, w}{\Sigma\, w} = 0.0716 \pm 0.0010$$

* See contribution No. II.

† See table of log ρ appended to this paper.

‡ See observations by Hossard at Angouleme, in May and June, 1844, from daybreak to twilight; of G. Davidson, assistant Coast Survey, at Bodega Head, Cal., in March, 1860, from 7 a. m. to 5 p. m.; and of F. W. Perkins, sub-assistant Coast Survey, at Ragged Mountain, Me., in July, August, and September, 1874, at all hours of day and night.

From the consistency of the above individual results of m we infer that no unusually large or small refraction obtained during the times of measures. The average height above the sea of the ten stations is 520 meters (1706 feet) very nearly. We possess no complete meteorological records in connection with the above measures. The value of $m = 0.0716$ will be used for lines observed only in one direction, as Academy to Northeast Base and Grassy to Kenesaw, and for the computation of heights of a number of secondary objects connected with this triangulation.*

2.—COMPUTATION OF HEIGHTS OF STATIONS FROM MEASURED DIFFERENCES OF HEIGHTS, WITH APPLICATION OF THE METHOD OF LEAST SQUARES.

The computation of the differences of heights from observed zenith-distances may be made by means of the following convenient formulæ:

For the case of reciprocal zenith-distances, either synchronous or not—

$$h_1 - h = s \tan \tfrac{1}{2} (\zeta_1 - \zeta)\left[1 + \frac{h + h_1}{2\rho} + \frac{s^2}{12\rho^2}\right] \ldots\ldots (1)$$

where h is the known height above the sea or the starting level for the measured difference of height and h_1 the height of the station opposite, s and ρ refer to the sea-level and $s \tan \frac{1}{2} (\zeta_1 - \zeta)$ furnishes an approximate value for h_1 to be used for the third term $\frac{h + h_1}{2\rho}$. The value of $\log \rho$ is taken from our table with the arguments, latitude, and azimuth of line.

For the case of zenith-distances observed upon only at one end of a line, which necessitates a knowledge or assumption of m—

$$h_1 - h = s \cot \zeta + \frac{1 - 2m}{2\rho} s^2 + \frac{1 - m}{\rho} s^2 \cot^2 \zeta$$

reducing by means of tabulated factors for various values of m to—

$$h_1 - h = s \cot \zeta + \mathrm{M} \frac{s^2}{\rho} + \mathrm{N} \frac{s^2 \cot^2 \zeta}{\rho} \ldots\ldots (2)$$

For the case under consideration our initial level is that of Stone Mountain, ascertained by means of spirit-levels to be $513^{m}.948$ above the half-tide level of the ocean. In connection with this operation executed partly under Assistant C. O. Boutelle's direction in 1873–'74, partly by the engineers of the railroad between Beaufort, S. C., and Augusta, Ga., the Port Royal and Beaufort levelings were connected directly with tidal observations. The results, expressed in feet, are as follows:

Height above mean sea-level.

Beaufort, S. C., bench-mark on wharf	6.85
Page's Point, S. C., mark on ground	19.44
Yemassee, S. C., mark on ground	22.93
Willow Oak, S. C., mark on ground	135.34
Augusta, Ga., stone post near Port Royal Railroad office	132.36
Stone Village, Ga., granite post front of Granite Company office	1037.44
Stone Mountain ground at C. S. △ station	1686.20

The spirit-levelings of the base-line in 1872–'73 gave the following results: Middle Base above Southwest Base 6.904 meters and Northeast Base above Southwest Base 7.684 meters; the base is

* For comparison of this value of m with other values referring to the sea-level (or to other levels) we may use Struve's pressure-factor $\frac{B}{736.6}$ where B equals the barometric reading expressed in millimeters. The average pressure at the sea-level in latitude $+34°$ is nearly 764^{mm}, and $48^{mm}.4$ less or $715^{mm}.6$ nearly at an altitude of 520^{m}, hence for the sea-level our value would become $0.0716 \frac{764}{715.6}$ or 0.0764 nearly, apparently a normal value. According to Bauernfeind's table, however, a change of $+1.9$ inches of pressure would change m from 0.0716 to 0.0773.

connected with Stone Mountain by means of zenith-distances. Our observations determine for 23 lines* the differences of heights from reciprocal measures for which consequently no knowledge of m is needed; for two remaining lines, Academy to Northeast Base and Grassy to Kenesaw, observed only at one end, we use the value of m as deduced above. These differences of height were computed by formulæ (1) and (2) with the following results arranged for positive differences, in each case the first-named station being the higher of the two:

Computed differences of heights from measures between ten stations.

		m.			m.
Stone Mountain	— Middle Base.... =	+ 188.78	Sawnee	— Stone Mountain ...... =	+ 86.30
Stone Mountain	— Southwest Base.	195.28	Sawnee	— Northeast Base.......	274.16
Stone Mountain	— Northeast Base.	188.21	Sawnee	— Academy	252.43
Sweat	— Stone Mountain.	3.76	Sawnee	— Kenesaw	46.27
Sweat	— Northeast Base.	190.14	Sawnee	— Sweat	83.85
Sweat	— Southwest Base.	197.52	Pine Log	— Sawnee...............	113.73
Stone Mountain	— Academy	167.69	Pine Log	— Kenesaw	161.52
Sweat	— Academy	169.87	Grassy	— Sweat	486.70
Pine Log	— Sweat	197.40	Grassy	— Sawnee...............	403.17
Kenesaw	— Sweat	35.24	Grassy	— Pine Log	289.61
Kenesaw	— Northeast Base.	224.62	Also—		
Kenesaw	— Southwest Base.	232.21	Academy	— Northeast Base.......	19.38
Kenesaw	— Stone Mountain.	38.49	Grassy	— Kenesaw	451.63

These results contain the unavoidable discrepancies due to errors of observations and to changes in refraction; they therefore call for a suitable method of combination and adjustment in order that we may assign the most probable values to the heights of the stations.

ADJUSTMENT OF RESULTS FOR DIFFERENCE OF HEIGHTS WITH APPLICATION OF THE METHOD OF LEAST SQUARES.

Supposing $h_1 - h_0 = \varDelta h_1$ a resulting difference of height between the two stations h_1 and h_0 determined either by zenith-distances at one or at both stations, then for any circuit of connecting heights or hypsometric linkage we must have the condition $\Sigma \varDelta h_1 = 0$; that is, if we start from any point h_0 and return to it through a series of intermediate connected differences of height this must bring us back to the starting level. Thus in any triangle in which the three differences of height are measured we have the condition—

$$0 = \varDelta h_1 + \varDelta h_2 + \varDelta h.$$

For convenience, the numbering may be from left to right (same as the turning of the hands of a watch).

In two triangles having one side in common we have—

$$0 = \varDelta h_1 + \varDelta h_2 + \varDelta h$$
$$0 = - \varDelta h + \varDelta h_3 + \varDelta h_4$$

the — sign being due to a change of direction. Adding these equations we obtain—

$$0 = \varDelta h_1 + \varDelta h_2 + \varDelta h_3 + \varDelta h_4$$

which is the condition for closing the circuit of a quadrilateral. We thus arrive at the important fact: In a geometrical figure composed of connected triangles it suffices to satisfy the conditions of the single triangles in order to have all other conditions satisfied. This materially simplifies the establishment of the conditional equations. In a triangle having three differences of heights measured we have one condition, in a quadrilateral with four differences of heights we have also one condition, in a quadrilateral with a diagonal and five differences of heights we have two conditions, in case of two diagonals and six differences of heights there are three conditions, the

* The line Southwest Base to Northeast Base is here omitted since the difference of height found by spirit-level ($7^m.684$) is far superior in accuracy to the value ($7^m.90$) found by the zenith-distances.

fourth circuit being satisfied by reason of the preceding three. In a quadrilateral with a central point and eight differences measured we have four conditions. In any circuit or linkage made up of n sides in which n differences of heights are measured we have but one condition; in short, for any circuit let p = number of connected points and m = number of measured differences of heights between any two of them, then number of conditions $= m - p + 1$.

If a series of hypsometrically connected points begins at one whose absolute elevation (above the sea) is known and terminates at another whose elevation is likewise known, it is obvious that there must be as many measured differences of heights as there are connecting links, and consequently there can be but one condition, hence for this case $m - p + 2$.

Absolute elevations are generally determined by means of the spirit-level, connecting them with a tide-gauge for which the reading of the half-tide or mean level of the ocean has become known from a series of tidal observations, extending rarely over less than one lunation. For greater precision two such series, half a year apart, should be employed. Where there is a large diurnal inequality in the tides the observations should be more extended and *successive* high and low waters $h_1\ l_2\ h_3\ l_4\ h_5\ l_6$ etc. may be combined as follows: Form successively the values $\frac{1}{8}(h_1 + 3\,l_2 + 3\,h_3 + l_4)$, $\frac{1}{8}(l_2 + 3\,h_3 + 3\,l_4 + h_5)$, $\frac{1}{8}(h_3 + 3\,l_4 + 3\,h_5 + l_6)$, etc. etc., each of which will be an approximation to the mean sea-level, and a series of such results will indicate the degree of convergence towards a mean value and give the means of judging of its probable error. Usually it suffices to take $\frac{1}{2}(\Sigma h - \Sigma l.)$

The coefficients of the conditional equations can be had by developing the expression of $h_1 - h$ according to Taylor's Theorem. Putting

$$\mathrm{H} = h_1 - h = s \cot \zeta + \frac{1 - 2\,m}{2\,\rho}\,s^2 + \frac{1 - m}{\rho}\,s^2 \cot^2 \zeta,$$

and differentiating with regard to s ζ and m, we have, with sufficient accuracy,

$$d\,\mathrm{H} = \cot \zeta\, d\,s - \frac{s}{\sin^2 \zeta}\,d\,\zeta - \frac{s^2}{\rho \sin^2 \zeta}\,d\,m.$$

This expression may be simplified by putting $d\,s = 0$, since, in all cases where the distances are known by triangulation, they are, or ought to be, known with greater accuracy than is needed for the purpose of determining heights; we can also put $\sin^2 \zeta = 1$, since ζ generally differs but little from 90°. We then obtain the following simple form for our conditional equations:

$$d\,\mathrm{H} = -\,s \sin 1''\,d\,\zeta - \frac{s^2}{\rho}\,d\,m$$

where $d\,\zeta$ is to be expressed in seconds. Owing to the irregular variations of m and our inability to compute it from observed meteorological conditions, it is, in general, not advisable to determine a correction ($d\,m$) to the introduced value of m. Since different values of m obtain, or may obtain, on different days, we approach closest to its actual values in the case of reciprocal observations, especially if synchronous, and the elimination of m in the computation of the differences of heights gives to the above equation the simple form* $d\,\mathrm{H} = -\,s \sin 1''\,d\,\zeta$. Even in the case of one zenith-distance to each line it is advisable to settle upon a value of m, guided rather by its value under similar circumstances than to deduce a correction to it from conditional equations. We shall, however, give an example of its introduction further on. Relative weights may be introduced according to the number of days of observation $n\ n_1$ at each end† of a line whence $w = \frac{n\,n_1}{n + n_1}$. Applying the

* This method is developed by General Bayer, see "Die Küstenvermessung und ihre Verbindung mit der Berliner Grundlinie, etc., etc.," von J. J. Bayer, etc., Berlin, 1849, pp. 434–437. The reader may also consult Schleiermacher's method, which takes into account the terms in $d\,\zeta$ and $d\,m$, as given in Dr. Ph. Fischer's "Lehrbuch der höheren Geodäsie," Darmstadt, 1845, Part III, pp. 186-199. It is presented in a form rather too heavy and inconvenient for general use, and is, moreover, complicated by the introduction of two sets of equations of correlatives, designed to obtain finally for solution a smaller number of equations—a process of doubtful utility.

† If observations are made at one end only, the relative weight will be $\frac{n}{4}$.

preceding method to the adjustment of height in the vicinity of the Atlanta Base, we arrange the computation as follows:

Computed difference of height.		Correction.	$-s$ arc 1″	w	Computed difference of height.		Correction.	$-s$ arc 1″	w
Designation.	Amount.				Designation.	Amount.			
	m.					m.			
h_7	+513.948	By spirit-level.			h_4-h_2	+232.21	v_{12}	−0.1288	2/3
h_1-h_2	6.904	By spirit-level.			h_4-h_7	38.49	v_{13}	.2148	2/3
h_3-h_1	0.780	By spirit-level.			h_6-h_7	86.30	v_{14}	.2316	1
h_7-h_1	188.78	v_1	−0.0797	2/3	h_6-h_3	274.16	v_{15}	.1669	2/3
h_7-h_2	195.28	v_2	.0861	1	h_6-h_{10}	252.43	v_{16}	.1675	1
h_7-h_3	188.21	v_3	.0791	2/3	h_6-h_4	46.27	v_{17}	.2338	2/3
h_5-h_7	3.76	v_4	.1974	2/3	h_6-h_5	83.85	v_{18}	.1604	2/3
h_5-h_3	190.14	v_5	.1222	1/2	h_9-h_6	113.73	v_{19}	.2175	2/3
h_5-h_2	197.52	v_6	.1181	2/3	h_9-h_4	161.52	v_{20}	.1876	3/4
h_7-h_{10}	167.69	v_7	.1076	1	h_8-h_5	486.70	v_{21}	.2322	2/3
h_5-h_{10}	169.87	v_8	.2161	2/3	h_8-h_6	403.17	v_{22}	.1543	1
h_9-h_5	197.40	v_9	.1591	3/4	h_8-h_9	289.61	v_{23}	.1625	2/3
h_4-h_5	35.24	v_{10}	.0738	1/2	$h_{10}-h_3$	19.38	v_{24}	.1106	1/2
h_4-h_3	224.62	v_{11}	−0.1557	1/2	h_8-h_4	451.63	v_{25}	−0.2958	1/2

Number of conditions.

Counting in the lines 2..1 and 1..3, but omitting the line 2..3, also including the lines 3..10 and 4..8, observed at one end only, we have $m = 27$ and $p = 10$, the point 1 counting, as well as 2 and 3; hence number of conditions among measured differences = 18.

Formation of conditional equations.

Circuit 2, 1, 7..
$$\begin{cases} h_2 - h_7 = -\ 195.28 + 0.0861\ v_2 \\ h_1 - h_2 = +\ \ \ 6.904 \\ h_7 - h_1 = +\ 188.78 - 0.0797\ v_1 \end{cases}$$
$$0 = +\ 0.404 - 0.0797\ v_1 + 0.0861\ v_2 \quad \ldots\ldots \quad \text{I.}$$

Circuit 1, 3, 7..
$$\begin{cases} h_3 - h_1 = +\ \ \ 0.780 \\ h_7 - h_3 = +\ 188.21 - 0.0791\ v_3 \\ h_1 - h_7 = -\ 188.78 + 0.0797\ v_1 \end{cases}$$
$$0 = +\ 0.210 - 0.0797\ v_1 - 0.0791\ v_3 \quad \ldots\ldots \quad \text{II.}$$

Circuit 2, 5, 7..
$$\begin{cases} h_5 - h_2 = +\ 197.52 - 0.1181\ v_6 \\ h_7 - h_5 = -\ \ \ 3.76 + 0.1974\ v_4 \\ h_2 - h_7 = -\ 195.28 + 0.0861\ v_2 \end{cases}$$
$$0 = -\ 1.52 + 0.0861\ v_2 + 0.1974\ v_4 - 0.1181\ v_6 \ldots\ldots \ \text{III.}$$

The remaining equations being formed in a similar manner are as follows:

$$0 = +\ 1.83 - 0.0791\ v_3 - 0.1974\ v_4 + 0.1222\ v_5 \ldots\ldots\ldots\ \text{IV.}$$
$$0 = +\ 1.56 - 0.0861\ v_2 + 0.1288\ v_{12} - 0.2148\ v_{13} \ldots\ldots\ldots\ \text{V.}$$
$$0 = -\ 0.55 + 0.1181\ v_6 + 0.0738\ v_{10} - 0.1288\ v_{12} \ldots\ldots\ldots\ \text{VI.}$$
$$0 = +\ 2.08 - 0.0791\ v_3 + 0.1557\ v_{11} - 0.2148\ v_{13} \ldots\ldots\ldots\ \text{VII.}$$
$$0 = -\ 1.14 + 0.0791\ v_3 - 0.1076\ v_7 - 0.1106\ v_{24} \ldots\ldots\ldots\ \text{VIII.}$$
$$0 = +\ 0.89 - 0.1222\ v_5 + 0.2161\ v_8 + 0.1106\ v_{24} \ldots\ldots\ldots\ \text{IX.}$$
$$0 = -\ 0.35 + 0.0791\ v_3 + 0.2316\ v_{14} - 0.1669\ v_{15} \ldots\ldots\ldots\ \text{X.}$$
$$0 = +\ 2.35 - 0.1669\ v_{15} + 0.1675\ v_{16} + 0.1106\ v_{24} \ldots\ldots\ldots\ \text{XI.}$$
$$0 = -\ 3.27 - 0.1557\ v_{11} + 0.1669\ v_{15} - 0.2338\ v_{17} \ldots\ldots\ldots\ \text{XII.}$$
$$0 = +\ 2.34 + 0.0738\ v_{10} + 0.2338\ v_{17} - 0.1604\ v_{18} \ldots\ldots\ldots\ \text{XIII.}$$
$$0 = +\ 2.19 + 0.2338\ v_{17} + 0.1543\ v_{22} - 0.2958\ v_{25} \ldots\ldots\ldots\ \text{XIV.}$$
$$0 = -\ 0.32 + 0.1604\ v_{18} - 0.2322\ v_{21} + 0.1543\ v_{22} \ldots\ldots\ldots\ \text{XV.}$$
$$0 = -\ 0.64 + 0.1591\ v_9 - 0.0738\ v_{10} - 0.1876\ v_{20} \ldots\ldots\ldots\ \text{XVI.}$$
$$0 = -\ 0.18 - 0.1591\ v_9 + 0.1604\ v_{18} + 0.2175\ v_{19} \ldots\ldots\ldots\ \text{XVII.}$$
$$0 = -\ 0.50 - 0.1876\ v_{20} - 0.1625\ v_{23} + 0.2958\ v_{25} \ldots\ldots\ldots\ \text{XVIII.}$$

Equations of correlatives.

$\frac{1}{w}$	v	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}
$\frac{3}{2}$	v_1	−.0797	+.0797																
1	v_2	+.0861		+.0861		−.0861													
$\frac{3}{2}$	v_3		−.0791		−.0791			−.0791	+.0791		+.0791								
$\frac{3}{2}$	v_4			+.1974	−.1974														
2	v_5				+.1222					−.1222									
$\frac{3}{2}$	v_6			−.1181			+.1181												
1	v_7								−.1076										
$\frac{3}{2}$	v_8									+.2161									
$\frac{4}{3}$	v_9																+.1591	−.1591	
2	v_{10}						+.0738							+.0738			−.0738		
2	v_{11}							+.1557					−.1557						
$\frac{3}{2}$	v_{12}					+.1288	−.1288												
$\frac{3}{2}$	v_{13}					−.2148		−.2148											
1	v_{14}										+.2316								
$\frac{3}{2}$	v_{15}										−.1669	−.1669	+.1669						
1	v_{16}											+.1675							
$\frac{3}{2}$	v_{17}												−.2338	+.2338	+.2338				
$\frac{3}{2}$	v_{18}													−.1604		+.1604		+.1604	
$\frac{5}{6}$	v_{19}																	+.2175	
$\frac{4}{3}$	v_{20}																−.1876		−.1876
$\frac{3}{2}$	v_{21}															−.2322			
1	v_{22}														+.1543	+.1543			
$\frac{5}{6}$	v_{23}																		−.1625
2	v_{24}								−.1106	+.1106		+.1106							
2	v_{25}														−.2958				+.2958

Normal equations.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}
0 = + 0.404	+.0169	−.0095	+.0074		−.0074													
0 = + 0.210	−.0095	+.0189		+.0094			+.0094	−.0094		−.0094								
0 = − 1.52	+.0074		+.0868	−.0584	−.0074	−.0209												
0 = + 1.83		+.0094	−.0584	+.0977			+.0094	−.0094	−.0299	−.0299								
0 = + 1.56	−.0074		−.0074		+.1015	+.0249	+.0692											
0 = − 0.55			−.0209		+.0249	+.0567							+.0109			−.0109		
0 = + 2.08		+.0094		+.0094	+.0692		+.1271	−.0094		−.0094		−.0485						
0 = − 1.14		−.0094		−.0094			−.0094	+.0454	−.0245	+.0094	−.0245							
0 = + 0.89				−.0299				−.0254	+.1244		+.0245							
0 = − 0.35		−.0094		−.0299			−.0094	+.0094		+.1048	+.0418	−.0418						
0 = + 2.35								−.0245	+.0245	+.0418	+.0943	−.0418						
0 = − 3.27							−.0485			−.0418	−.0418	+.1723	−.0820	−.0820				
0 = + 2.34						+.0109						−.0820	+.1315	+.0820	−.0386	−.0109	−.0386	
0 = + 2.19												−.0820	+.0820	+.2808	+.0238			−.1750
0 = − 0.32													−.0386	+.0238	+.1433		+.0386	
0 = − 0.64						−.0109							−.0109			+.0916	−.0338	+.0469
0 = − 0.18													−.0386		+.0386	−.0338	+.1118	
0 = − 0.50														−.1750		+.0469		+.2439

Resulting values of the correlatives.

$C_1 = -57.513$	$C_4 = +4.264$	$C_7 = -8.831$	$C_{10} = +13.493$	$C_{13} = -14.231$	$C_{16} = +9.319$
$C_2 = -31.723$	$C_5 = -5.718$	$C_8 = -1.378$	$C_{11} = -29.360$	$C_{14} = -4.095$	$C_{17} = -0.186$
$C_3 = +30.311$	$C_6 = +22.892$	$C_9 = -0.620$	$C_{12} = +3.920$	$C_{15} = -0.870$	$C_{18} = -2.680$

These values satisfy the equations.

In the following tables are given the corrections $v_1\ v_2\ v_3 \ldots\ldots$ * to the observed zenith-distances, also the corresponding corrections to the differences of heights,† the corrected differences, and the absolute heights.

Correction to ζ or $d\,\zeta$.	d H.	Corrected differences of heights.	Correction to ζ or $d\,\zeta$.	d H.	Corrected differences of heights.
$''$	$m.$	$m.$	$''$	$m.$	$m.$
$v_1 = +3.083$	-0.246	$h_7 - h_1 = +188.534$	$v_{14} = +3.125$	-0.724	$h_6 - h_7 = +85.576$
$v_2 = -1.850$	$+0.159$	$h_7 - h_2 = 195.439$	$v_{15} = +4.955$	-0.827	$h_6 - h_3 = 273.333$
$v_3 = +5.743$	-0.454	$h_7 - h_3 = 187.756$	$v_{16} = -4.918$	$+0.824$	$h_6 - h_{10} = 253.254$
$v_4 = +7.712$	-1.522	$h_5 - h_7 = 2.238$	$v_{17} = -7.802$	$+1.824$	$h_6 - h_4 = 48.094$
$v_5 = +1.194$	-0.146	$h_5 - h_3 = 189.994$	$v_{18} = +3.170$	-0.508	$h_6 - h_5 = 83.342$
$v_6 = -1.314$	$+0.155$	$h_5 - h_2 = 197.675$	$v_{19} = -0.034$	$+0.007$	$h_9 - h_6 = 113.737$
$v_7 = +0.148$	-0.016	$h_7 - h_{10} = 167.674$	$v_{20} = -1.660$	$+0.311$	$h_9 - h_4 = 161.831$
$v_8 = -0.201$	$+0.043$	$h_5 - h_{10} = 169.913$	$v_{21} = +0.303$	-0.070	$h_8 - h_5 = 486.630$
$v_9 = +2.016$	-0.321	$h_9 - h_5 = 197.079$	$v_{22} = -0.766$	$+0.118$	$h_8 - h_6 = 403.288$
$v_{10} = -0.097$	$+0.007$	$h_4 - h_5 = 35.247$	$v_{23} = +0.363$	-0.059	$h_8 - h_9 = 289.551$
$v_{11} = -3.971$	$+0.618$	$h_4 - h_3 = 225.238$	$v_{24} = -6.327$	$+0.700$	$h_{10} - h_3 = 20.080$
$v_{12} = -5.527$	$+0.712$	$h_4 - h_2 = 232.922$	$v_{25} = +0.837$	-0.248	$h_8 - h_4 = 451.382$
$v_{13} = +4.688$	-1.007	$h_4 - h_7 = 37.483$			

The corrections $v_1\ v_2\ v_3 \ldots\ldots$ apply directly to $\frac{1}{2}(\zeta_1 - \zeta)$ or singly to the observed ζ_1 and ζ of each line respectively, with the given sign to the smaller zenith-distance and with its sign reversed to the larger zenith-distance. Thus, for example, in the case of v_3 referring to difference of height $h_7 - h_3$

$$\zeta_3 = 89^\circ\ 24'\ 04''.0 + 5''.743 = 89^\circ\ 24'\ 09''.743 = \text{corrected zenith-distance at Northeast Base.}$$
$$\zeta_7 = 90^\circ\ 43'\ 20''.8 - 5''.743 = 90^\circ\ 43'\ 15''.057 = \text{corrected zenith-distance at Stone Mountain.}$$

$$\tfrac{1}{2}(\zeta_7 - \zeta_3) = +\ 2372''.657$$

and by formula (1) $h_7 - h_3 = +\ 187^{\text{m}}.756$, same as given in the table.

Resulting heights (surface of ground at center of mark).

		m.	feet.
Middle Base	$h_1 =$	325.414 =	1067.64
Southwest base	$h_2 =$	318.510	1044.99
Northeast Base	$h_3 =$	326.192	1070.19
Kenesaw	$h_4 =$	551.432	1809.18
Sweat Mountain	$h_5 =$	516.186	1693.54
Sawnee	$h_6 =$	599.526	1966.97
Stone Mountain	$h_7 =$	513.948	1686.20
Grassy	$h_8 =$	1002.814	3290.10
Pine Log	$h_9 =$	713.263	2340.12
Academy	$h_{10} =$	346.274	1136.08

DETERMINATION OF THE PROBABLE ERROR OF THE RESULTING HEIGHTS.

To determine the probable errors strictly, as required by the method of least squares, would be unnecessarily laborious. It is therefore proposed to substitute, in our case, the following more simple process, possessing all requisite accuracy for our purpose:

Squaring the angular corrections $d\,\zeta$ as found by the preceding adjustment, and taking the square root of the average square, we find the average error of a zenith-distance $= \pm\ 3''.77$. How-

* As found by the usual equations of the form $v = \frac{1}{p}(a\,C_1 + b\,C_2 + c\,C_3 + \ldots\ldots)$. These corrections are given in the above table in the column headed "Correction to ζ or $d\,\zeta$" expressed in seconds.

† Found by $d\,H = -s$ arc $1''\ d\,\zeta$ expressed in meters.

ever, in connection with the use of equations of correlatives, we use the formula for the mean error $m = \sqrt{\frac{[v\,v]}{n_c}}$ when $n_c =$ the number of conditions which had to be strictly satisfied. We find $m = \pm\ 4''.44$, hence the probable error ε_ζ of a zenith-distance $= \pm\ 3''.00$. This amount is principally due to variations in refraction and subordinately only to errors of observation; supposing, however, an equality of effect from these two independent sources of error, each would be $\frac{3.00}{\sqrt{2}} = \pm\ 2''.12$, a small value.

To compute the probable error $\varepsilon_{\Delta h}$ in any measured difference of height, we have

$$\varepsilon_{\Delta h} = \mp\ s \text{ arc } 1''\ \varepsilon_\zeta.$$

For lines occupied only at one end, we must add to this expression the effect of the uncertainty in the adopted coefficient of refraction or $\mp \frac{s^2}{\rho}\ \varepsilon_m$; the value of ε_m previously found is $\pm\ 0.0010$; hence the formula

$$\varepsilon_{\Delta h} = \sqrt{\left(s \text{ arc } 1''\ \varepsilon_\zeta\right)^2 + \left(\frac{s^2}{\rho}\ \varepsilon_m\right)^2}.$$

The value of $\varepsilon_{\Delta h}$ for each line* is given in the following table:

Measured difference of height.	Probable error.	Measured difference of height.	Probable error.	Measured difference of height.	Probable error.	
	m.		m.		″	
$h_7 - h_1$	±0.239	$h_9 - h_5$	±0.477	$h_6 - h_4$	±0.701	
$h_7 - h_2$	.258	$h_4 - h_5$	.221	$h_8 - h_5$	.481	
$h_7 - h_3$	.237	$h_4 - h_3$	.467	$h_9 - h_6$	.652	
$h_5 - h_7$	.592	$h_4 - h_2$	.386	$h_9 - h_4$	.563	
$h_5 - h_3$	.367	$h_4 - h_7$	.644	$h_8 - h_5$	.697	
$h_5 - h_2$	.354	$h_6 - h_7$	.695	$h_8 - h_6$	.463	
$h_7 - h_{10}$	.323	$h_6 - h_3$	.501	$h_8 - h_9$	.487	″ ″
$h_5 - h_{10}$	.648	$h_8 - h_{10}$	.502	$h_{10} - h_3$	.332	$\mp$ 0.081 = ± 0.342
				$h_8 - h_4$	.887	$\mp$ 0.585 = ± 1.063

If $\varepsilon_h =$ probable error of height of any one starting point and $\varepsilon_{\Delta h} =$ probable error of difference of height of a point determined from it, then the probable error of this last point will be given by $\sqrt{\varepsilon^2_h + \varepsilon^2_{\Delta h}}$.

We now compute the probable error in height of each point successively (and, if need be, by successive approximations), commencing with the first one of known height (generally given by spirit-level), next taking that adjacent point which is best determined from it, and so on, always selecting the points in the order of least error, mainly depending on shortness of side and on number of connections, with other surrounding points already disposed of. Owing to the mutual support of two or more connected points, it will, in general, be necessary to determine first a preliminary probable error for each. Let $\varepsilon_1\ \varepsilon_2\ \varepsilon_3\ \ldots$ equal the probable errors obtained for the same point from a number of surrounding points and connected with it, then, under the supposition that the several determinations are independent of each other, the probable error of its height will be

$$\varepsilon = \frac{1}{\sqrt{\frac{1}{\varepsilon^2_1} + \frac{1}{\varepsilon^2_2} + \frac{1}{\varepsilon^2_3} + \ldots}};$$

or, by making use of the weights $\left(w = \frac{1}{\varepsilon^2}\right)$, its weight will be $w = w_1 + w_2 + w_3 + \ldots$

* The average distance being nearly 33 kilometers, the average probable error of a difference of height becomes $\pm\ 0^m.487$, which is nearly $\frac{1}{68000}$ of the horizontal distance.

This formula, however, must be used with great caution, since, in reality, the probable errors assigned to stations, preceding, do not generally possess such independence as it supposes; in fact, this independence occurs only exceptionally. In all cases where the mutual interlacings of the differences of heights are disregarded, the above formula would lead to erroneous and contradictory probable errors; for instance, such as giving a smaller probable error to a subsequent station than the probable error of a preceding station on which it depends.

On the other hand, if we advance from station to station, along a direct and single route by the combination of ε_h $\varepsilon_{\Delta h_1}$ $\varepsilon_{\Delta h_{11}}$ &c., and finally for the last station combine the starting—and the accumulated probable errors or $\sqrt{\varepsilon^2_h + \varepsilon^2_{\Delta h_{11}}}$ we should fall into the error of neglecting the mutual support given each height by those surrounding it; in other words, we should neglect the effect of all other routes besides the direct one used, and our probable error would necessarily be too large; whereas in our first supposition of independence of data the resulting probable error would be too small. It will thus be seen that a judicious combination of the two ways of arriving at an approximate evaluation of the probable uncertainty in the heights assigned, must be made by the computer, who will be guided by special considerations, meeting the exigencies of special cases as they present themselves.

The probable error ε_7, or that of Stone Mountain, which depends on a leveling operation, is common to all the heights, and has been estimated to equal $\pm$ 0m.35; it will be added at the end to the relative probable errors found as follows:

For each of the three base-line stations the probable error must be the same, since we consider the spirit-leveling perfect in comparison with measures of vertical angles; it is therefore equivalent to the combination of three measures for the same point, having the probable errors

$$\pm 0^{m}.239 \quad \pm 0^{m}.258 \quad \pm 0^{m}.237;$$

hence—

$$\varepsilon = \pm 0^{m}.141,$$

which answers for Southwest Base, for Middle Base, and for Northeast Base. The next best determined height is Sweat Mountain, having three lines to it, each shorter than the corresponding lines to Kenesaw.

Sweat Mountain.

	m.	*m.*		*m.*
From Stone Mountain	± 0.000	± 0.592	=	± 0.592
From Southwest Base	± 0.141	± 0.354	=	± 0.382
From Northeast Base	± 0.141	± 0.367	=	± 0.393

where the first probable error is that of the starting station, the second that of the measured difference of height, and the third the resulting probable error of Sweat Mountain by each of the three converging lines. Combining the above three values we obtain the first approximation,

$$\varepsilon_5 = \pm 0^{m}.249.$$

Similarly:

Kenesaw.

From Stone Mountain....	±0m.000	±0m.644	±0m.644	First approximation, $\varepsilon_4 = \pm 0^{m}.282$.
From Southwest Base....	±0m.141	±0m.386	±0m.411	
From Northeast Base	±0m.141	±0m.467	±0m.448	

Now, introducing this fourth line, Kenesaw to Sweat, we have for Kenesaw and the measured difference ±0m.282 ±0m.221 =±0m.358, and combining this with the first three values, we obtain finally $\varepsilon_5 = \pm 0^{m}.204$.

Similarly for Kenesaw: For Sweat and the measured difference ±0m.249 ±0m.221 = ±0m.333; hence from 4 converging lines $\varepsilon_4 = \pm 0^{m}.215$.

We next treat Sawnee and Academy, and lastly Pine Log and Grassy, with the following results:

	Prob. error relative to Stone Mountain.	Final prob. error of height.
	m.	*m.*
Stone Mountain	± 0.000	± 0.350
Southwest Base	0.141	0.377
Middle Base	0.141	0.377
Northeast Base	0.141	0.377
Sweat Mountain	0.204	0.405
Kenesaw	0.215	0.411
Academy	0.209	0.408
Sawnee	0.266	0.440
Pine Log	0.301	0.462
Grassy	0.332	0.482

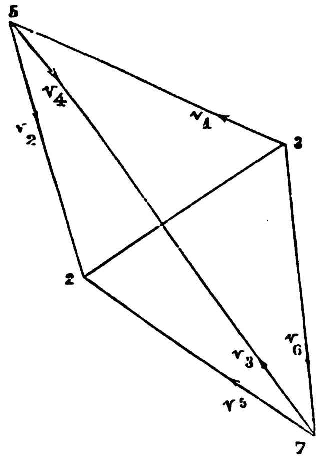
ADDITIONAL REMARKS AND EXAMPLES FOR ADJUSTMENT OF HEIGHTS MEASURED UNDER CONDITIONS DIFFERENT FROM THOSE OBTAINING ABOVE.

To render this communication more generally useful the following examples of adjustment are introduced, suiting other conditions or requirements than those subsisting in the vertical measures treated above.

(*a.*) Determination of a correction to an assumed value of the coefficient of refraction to be found from the conditions among the measured differences of height.

In this case it is essential that the connecting lines (horizontal distances) should vary greatly in length. The weight of any measured difference, Δh, diminishes with increasing distance and may be taken proportional to $\frac{1}{s}$, but with respect to the coefficient of refraction the weight will be *inversely* proportional to the *square* of the distance (see preceding formula for ϵ), showing how rapidly with increase of distance any error in m will affect injuriously the value of Δh, for which reason it has been found necessary, for refined work, to keep the distance between vertical angle-stations confined within certain practical limits. Very accurate results may be had if the distances do not exceed 24 kilometers (about 15 statute miles), and satisfactory results may yet be expected with limits inside of 40 and even 50 kilometers (25 and 31 statute miles respectively). Beyond these limits the value of the work may be improved by increasing the number of days of observations (always confined within the favorable hours of the day), and by increasing the number of conditions or links and by simultaneous reciprocal observations, or generally by spirit-level checks.

We cull the following example from measures already employed.



Given, difference of height $h_3 - h_2 = + 7^m.684$ by spirit-level. $h_7 = 513^m.948$ absolute height above half-tide level of the ocean, and the following 6 measured zenith-distances, as shown in the annexed cut:

			n.	*Corr'n.*
At station 3:				
	ζ to 5	89° 39′ 51″.7	1	v_1
At station 5:				
	ζ to 2	90° 33′ 37″.2	1	v_2
	to 7	90° 09′ 37″.0	1	v_4
At station 7:				
	ζ to 2	90° 41′ 56″.8	2	v_5
	to 3	90° 43′ 20″.8	2	v_6
	to 5	90° 08′ 58″.9	2	v_3

also log. distances (expressed in meters) and log. curvature.

	log. s.	log. ρ.
2 . . 5	4.38683	6.80370
3 . . 5	4.40149	6.80448
2 . . 7	4.24947	6.80473
3 . . 7	4.21274	6.80364
5 . . 7	4.60988	6.80414

With $m = 0.0716 + v_0$ and the above values of ζ we compute the differences Δh, also the coefficients $s \sin 1''$ and $\frac{s^2}{\rho}$, and find

$$\left\{\begin{array}{l} m. \\ h_5 - h_3 = +\ 190.40 - 0.1222\ v_1 - 99.65\ v_0 \\ h_5 - h_2 = +\ 198.29 - 0.1181\ v_2 - 93.32\ v_0 \\ h_5 - h_7 = +\ 5.29 - 0.1975\ v_3 - 260.38\ v_0 \\ h_7 - h_5 = -\ 2.23 + 0.1975\ v_4 + 260.38\ v_0 \\ h_7 - h_2 = +\ 195.50 - 0.0861\ v_5 - 49.45\ v_0 \\ h_7 - h_3 = +\ 187.83 - 0.0791\ v_6 - 41.86\ v_0 \end{array}\right.$$

The circuits 2, 3, 7; 2, 5, 3, and 2, 5, 7, and the measures at the ends of the line 5 . . 7 furnish the following four conditional equations in which the value $V = 100\ v_0$ has been introduced to facilitate the numerical work:

Conditional equations:

$$\left\{\begin{array}{llllll} 0 = +\ 0.014 + 0.0759\ V & & & & + 0.0861\ v_5 & - 0.0791\ v_6 \\ 0 = +\ 0.206 + 0.0633\ V & + 0.1222\ v_1 & - 0.1181\ v_2 & & & \\ 0 = -\ 2.500 + 2.1651\ V & & - 0.1181\ v_2 & + 0.1975\ v_3 & + 0.0861\ v_5 & \\ 0 = +\ 3.060 & & & - 0.1975\ v_3 + 0.1975\ v_4 & & \end{array}\right.$$

If we do not intend to introduce special weights with respect to number of observations or days of observation, that is, if we suppose $n = 1$, we may complete the process of computation by forming the equations of correlatives and the normal equations and their solution will give the following values and results:

$$\begin{array}{llll} & & '' & m. \\ C_1 = -\ 4.172 & \left\{\begin{array}{l} V = +\ 0.503 \\ v_0 = +\ 0.0050 \\ m = \ 0.0766 \end{array}\right. & \left\{\begin{array}{l} v_1 = -\ 1.04 \\ v_2 = +\ 0.93 \\ v_3 = +\ 7.81 \\ v_4 = -\ 7.68 \\ v_5 = -\ 0.31 \\ v_6 = +\ 0.33 \end{array}\right. & \left\{\begin{array}{l} h_5 - h_3 = +\ 190.031 \\ h_5 - h_2 = +\ 197.715 \\ h_5 - h_7 = +\ 2.438 \\ h_7 - h_5 = -\ 2.437 \\ h_7 - h_2 = +\ 195.279 \\ h_7 - h_3 = +\ 187.595 \end{array}\right. \\ C_2 = -\ 8.544 & & & \\ C_3 = +\ 0.6283 & & & \\ C_4 = -\ 38.91 & & & \end{array}$$

and

$$\left\{\begin{array}{l} m. \\ h_7 = 513.948 \\ h_5 = 516.385 \\ h_3 = 326.353 \\ h_2 = 318.669 \end{array}\right.$$

But if special weights are to be introduced depending on number of observations, we have first to eliminate V from the above conditional equations and find—

$$\left\{\begin{array}{llll} 0 = +\ 0.2330 + 0.1465\ v_1 - 0.1416\ v_2 & & & - 0.0861\ v_5 + 0.0791\ v_6 \\ 0 = +\ 2.8994 & + 0.1181\ v_2 - 0.1975\ v_3 & & + 2.3700\ v_5 - 2.2564\ v_6 \\ 0 = +\ 3.0600 & & - 0.1975\ v_3 + 0.1975\ v_4 & \end{array}\right.$$

hence the equations of correlatives and normal equations:

Correlatives.

$\frac{1}{n}$		C_1	C_2	C_3
1	v_1	+0.1465		
1	v_2	−0.1416	+0.1181	
0.5	v_3		−0.1975	−0.1975
1	v_4			+0.1975
0.5	v_5	−0.0861	+2.3700	
0.5	v_6	+0.0791	−2.2564	

Normal equations.

$$\begin{cases} 0 = +0.2330 + 0.04835\,C_1 - 0.00799\,C_2 \\ 0 = +2.8994 - 0.20799\,C_1 + 5.38757\,C_2 + 0.01950\,C_3 \\ 0 = +3.0600 \qquad\qquad + 0.01950\,C_2 + 0.05851\,C_3 \end{cases}$$

$$\begin{cases} C_1 = -\ 7.5823 \\ C_2 = -\ 0.6424 \\ C_3 = -52.084 \end{cases} \qquad \begin{cases} v_1 = -\ 1.11'' \\ v_2 = +\ 1.00 \\ v_3 = +\ 5.21 \\ v_4 = -10.29 \\ v_5 = -\ 0.43 \\ v_6 = +\ 0.42 \end{cases}$$

Comparing these values with the corresponding preceding ones, we notice but trifling changes excepting in v_3 and v_4, on which the introduced weights have acted most conspicuously.

To find the value of V we may substitute in any one of the original conditional equations, the third gives V = + 0.76, hence $v_0 = +0.0076$ and $m = 0.0792$.

$$\text{Finally, we have } h_7 = 513.95 \text{ nearly.}^{\,m.}$$
$$h_5 = 516.24$$
$$h_3 = 326.46$$
$$h_2 = 318.78$$

(*b.*) Cases will often occur in practice which, from their nature, do not require any very refined and laborious process of adjustment; we may be satisfied with a moderate degree of approximation to the most probable values in cases of vertical measures in tertiary triangulation, or in hypsometric reconnaissances, or even in plane-table practice for the location of contour-lines. Excepting the reconnaissances, the sides will then be so short that any small defect in the adopted value of the coefficient of refraction will have no sensible influence on the resulting difference of heights.

We may therefore assume that the value of m is sufficiently well known to require no further improvement, and may operate directly on the computed differences of heights, still employing suitable weights according to the formula $\frac{n}{s}$ or the formula $\frac{1}{s}\cdot\frac{nn_1}{n+n_1}$, the first for measures of a zenith-distance at *one* end of a line, the second for zenith-distances at both ends. Our principal object will be to disperse the existing small contradictions in the computed differences and thus to render them consistent among themselves.

Resuming the above example, and supposing the differences of height, deduced from the measures, subject to corrections v_1 v_2 . . .

We have given:

$$\begin{cases} h_7 = 513.948^{\,m.} \\ h_3 - h_2 = +7.684 \end{cases} \text{and} \begin{cases} h_5 - h_3 = +190.40^{\,m.} + v_1, & \text{also } w = \frac{n}{s} = \frac{1}{25.20} \\ h_5 - h_2 = +198.29 + v_2 & \frac{1}{24.37} \\ h_5 - h_7 = +\ \ 5.29 + v_3 & \frac{2}{40.73} \\ h_7 - h_5 = -\ \ 2.23 + v_4 & \frac{1}{40.73} \\ h_7 - h_2 = +195.50 + v_5 & \frac{2}{17.76} \\ h_7 - h_3 = +187.83 + v_6 & \frac{2}{16.32} \end{cases}$$

s being expressed in kilometers.

Conditional equations.

$$\begin{cases} 0 = -0.014 + v_5 - v_6 \\ 0 = -0.206 + v_1 - v_2 \\ 0 = +2.500 - v_2 + v_3 + v_5 \\ 0 = -3.060 - v_3 - v_4 \end{cases}$$

Equations of correlatives.

$w^{-1} = \frac{s}{n}$		C_1	C_2	C_3	C_4
25.20	v_1		+1		
24.37	v_2		−1	−1	
20.36	v_3			+1	−1
40.73	v_4				−1
8.88	v_5	+1		+1	
8.16	v_6	−1			

Normal equations.

$$\begin{cases} 0 = -0.014 + 17.04\,C_1 + 8.88\,C_3 \\ 0 = -0.206 + 49.57\,C_2 + 24.37\,C_3 \\ 0 = +2.500 + 8.88\,C_1 + 24.37\,C_2 + 53.61\,C_3 - 20.36\,C_4 \\ 0 = -3.060 - 20.36\,C_3 + 61.09\,C_4 \end{cases}$$

$$\begin{cases} C_1 = +0.02822 \\ C_2 = +0.03001 \\ C_3 = -0.05258 \\ C_4 = +0.03256 \end{cases} \qquad \begin{cases} v_1 = +0.756 \\ v_2 = +0.550 \\ v_3 = -1.733 \end{cases} \text{m.} \qquad \begin{matrix} v_4 = -1.326 \\ v_5 = -0.218 \\ v_6 = -0.231 \end{matrix} \text{m.}$$

Hence—

$$\begin{cases} h_5 - h_3 = +191.156 \\ h_5 - h_2 = +198.840 \\ h_5 - h_7 = +\ \ 3.557 \\ h_7 - h_5 = -\ \ 3.556 \\ h_7 - h_2 = +195.282 \\ h_7 - h_3 = +187.599 \end{cases} \text{m.} \quad \text{and} \quad \begin{cases} h_7 = 513.948 \\ h_5 = 517.505 \\ h_3 = 326.349 \\ h_2 = 318.665 \end{cases} \text{m.}$$

This last method recommends itself by its comparative simplicity and tolerable approximation to close accuracy. By omitting weights the results would lose considerably in value; although unity may be substituted for n, the fac'oı $\frac{1}{s}$ should never be omitted.

The following tables for log M, log N, and log ρ are appended to facilitate computations of heights. They depend upon the formulæ

$$M = \frac{1 - 2m}{2} \qquad N = 1 - m \qquad e^2 = \frac{a^2 - b^2}{a^2}$$

Radius of curvature in meridian $\dfrac{a(1 - e^2)}{(1 - e^2 \sin^2 \varphi)^{\frac{3}{2}}}$

Radius of curvature perpendicular to it $\dfrac{a}{(1 - e^2 \sin^2 \varphi)^{\frac{1}{2}}}$

Radius of curvature in azimuth a* $\dfrac{a(1 - e^2)}{(1 - e^2 + e^2 \cos^2 a \cos^2 \varphi)(1 - e^2 \sin^2 \varphi)^{\frac{1}{2}}}$

where $a = 6378206$ meters $\log a = 6.8046985$
$b = 6356584$ meters $\log b = 6.8032238$
$\log e^2 = 7.83047$

See "Comparisons of Standards of Lengths," etc., by Capt. A. R. Clarke, R. E., London, 1866, p. 287.

---

* In terms of radius of meridian ρ_m and of perpendicularity ρ_p, the radius of curvature in azimuth equals

$$\rho_a = \frac{\rho_m \rho_p}{\rho_m \sin^2 a + \rho_p \cos^2 a}; \text{ also } \rho_{45} = \frac{2 \rho_0 \rho_{90}}{\rho_0 + \rho_{90}}$$

Table of log M and log N.

m	Log M.	Δ	Log N.	m	Log M.	Δ	Log N.
0.050	9.65321	96	9.978	0.080	9.62325	104	9.964
51	65225		77	81	62221		63
52	65128		77	82	62118		63
53	65031		76	83	62014		62
54	64933	97	76	84	61910	105	62
55	64836		75	85	61805		61
56	64738		75	86	61700		61
57	64640		75	87	61595		60
58	64542	98	74	88	61490	106	60
59	64444		74	89	61384		60
0.060	9.64345	99	9.973	0.090	9.61278	106	9.959
61	64246		73	91	61172		59
62	64147		72	92	61066		58
63	64048		72	93	60959		58
64	63949	100	71	94	60853	107	57
65	63849		71	95	60746		57
66	63749		70	96	60638		56
67	63649		70	97	60531		56
68	63548	100	69	98	60423	108	55
69	63448		69	99	60315		55
0.070	9.63347	101	9.968	0.100	9.60206		9.954
71	63246		68				
72	63144		68				
73	63043		67				
74	62941	102	67				
75	62839		66				
76	62737		66				
77	62634		65				
78	62531	103	65				
79	62428		64				

Table of logarithms of radius of curvature to the earth's surface for various latitudes and azimuths, based upon Clarke's ellipsoid of rotation (1866), *and for metric unit.*

Azimuth.	LATITUDE.									
	22°	23°	24°	25°	26°	27°	28°	29°	30°	31°
°										
Meridian 0	6. 802368	6. 802423	6. 802479	6. 802537	6. 802597	6. 802659	6. 802722	6. 802786	6. 802852	6. 802919
5	2387	2442	2498	2556	2615	2676	2739	2803	2869	2936
10	2444	2498	2553	2610	2669	2730	2791	2854	2919	2985
15	2538	2590	2644	2699	2756	2815	2875	2937	3000	3064
20	2664	2714	2766	2820	2875	2932	2990	3050	3111	3173
25	2820	2868	2918	2969	3022	3076	3131	3188	3246	3306
30	3001	3046	3093	3142	3192	3243	3296	3350	3405	3461
35	3201	3244	3288	3333	3380	3428	3477	3528	3580	3632
40	3414	3454	3495	3537	3580	3625	3671	3718	3766	3815
45	3635	3672	3709	3748	3788	3829	3871	3914	3958	4003
50	3856	3889	3923	3958	3994	4031	4070	4109	4150	4191
55	4069	4099	4130	4162	4195	4229	4264	4300	4337	4374
60	4271	4297	4325	4354	4384	4415	4446	4479	4512	4546
65	4451	4475	4500	4527	4554	4582	4610	4640	4669	4700
70	4608	4630	4653	4678	4702	4727	4753	4780	4807	4835
75	4734	4755	4776	4799	4822	4845	4869	4893	4918	4943
80	4828	4847	4867	4888	4909	4931	4953	4976	4999	5023
85	4886	4904	4923	4943	4963	4984	5006	5027	5049	5073
Perpendicular 90	4905	4923	4942	4961	4981	5002	5023	5044	5066	5089

Azimuth.	LATITUDE.									
	32°	33°	34°	35°	36°	37°	38°	39°	40°	41°
°										
Meridian 0	6. 802988	6. 803058	6. 803129	6. 803201	6. 803274	6. 803348	6. 803422	6. 803497	6. 803573	6. 803650
5	3004	3074	3145	3217	3289	3362	3436	3511	3586	3662
10	3052	3120	3190	3261	3332	3405	3478	3552	3626	3701
15	3130	3197	3265	3334	3404	3475	3546	3618	3690	3763
20	3236	3300	3366	3432	3500	3568	3637	3706	3776	3847
25	3367	3428	3491	3554	3619	3684	3749	3815	3882	3949
30	3518	3576	3636	3696	3757	3818	3880	3943	4006	4070
35	3686	3740	3796	3852	3909	3967	4025	4083	4142	4202
40	3864	3915	3967	4019	4072	4125	4179	4234	4289	4344
45	4049	4095	4143	4191	4239	4288	4338	4388	4439	4490
50	4233	4276	4319	4363	4407	4452	4498	4544	4590	4636
55	4412	4451	4490	4530	4570	4611	4652	4694	4736	4778
60	4580	4615	4650	4686	4723	4760	4797	4835	4873	4911
65	4731	4763	4795	4828	4861	4894	4928	4962	4996	5031
70	4863	4892	4921	4950	4980	5010	5041	5072	5104	5135
75	4969	4995	5022	5049	5076	5104	5133	5161	5190	5219
80	5047	5072	5097	5122	5148	5174	5201	5227	5254	5281
85	5096	5119	5143	5168	5192	5217	5242	5268	5294	5319
Perpendicular 90	5112	5135	5159	5183	5207	5231	5256	5281	5307	5332

Table of logarithms of radius of curvature to the earth's surface for various latitudes and azimuths, based upon Clarke's ellipsoid of rotation (1866), *and for metric unit*—Continued.

Azimuth.	LATITUDE.									
	42°	43°	44°	45°	46°	47°	48°	49°	50°	51°
°										
Meridian 0	6.803726	6.803803	6.803880	6.803957	6.804035	6.804112	6.804189	6.804265	6.804342	6.804418
5	3739	3815	3892	3968	4045	4122	4199	4275	4351	4427
10	3775	3850	3926	4001	4077	4153	4228	4303	4378	4452
15	3835	3908	3982	4056	4130	4204	4277	4350	4423	4495
20	3917	3988	4059	4130	4201	4272	4343	4413	4484	4554
25	4017	4085	4153	4221	4289	4357	4425	4492	4559	4626
30	4133	4197	4262	4327	4391	4455	4519	4583	4647	4710
35	4262	4322	4382	4443	4503	4563	4623	4683	4743	4802
40	4400	4456	4511	4567	4623	4679	4735	4791	4846	4901
45	4541	4592	4643	4695	4747	4798	4849	4900	4951	5002
50	4683	4730	4777	4824	4871	4918	4965	5012	5058	5104
55	4820	4862	4905	4948	4991	5033	5076	5118	5161	5203
60	4949	4987	5025	5064	5104	5143	5181	5219	5257	5295
65	5066	5100	5135	5170	5205	5240	5275	5310	5345	5379
70	5166	5197	5229	5261	5293	5325	5357	5389	5420	5451
75	5248	5277	5307	5335	5364	5394	5423	5452	5481	5510
80	5308	5335	5363	5390	5417	5445	5472	5499	5526	5553
85	5345	5371	5397	5424	5450	5476	5502	5528	5554	5579
Perpendicular 90	5358	5383	5409	5435	5460	5486	5512	5537	5563	5588

Azimuth.	LATITUDE.								
	52°	53°	54°	55°	56°	57°	58°	59°	60°
°									
Meridian 0	6.804493	6.804567	6.804641	6.804714	6.804786	6.804858	6.804928	6.804997	6.805064
5	4502	4576	4649	4722	4794	4865	4934	5003	5070
10	4526	4599	4672	4743	4814	4884	4953	5021	5087
15	4568	4639	4710	4779	4848	4915	4983	5049	5114
20	4624	4693	4761	4828	4894	4959	5025	5089	5151
25	4692	4758	4823	4888	4951	5014	5076	5137	5197
30	4773	4835	4896	4957	5017	5076	5135	5193	5249
35	4861	4919	4977	5034	5090	5146	5201	5254	5306
40	4955	5009	5063	5116	5168	5219	5270	5320	5370
45	5052	5101	5151	5199	5247	5295	5342	5388	5432
50	5150	5195	5240	5284	5328	5372	5415	5457	5498
55	5244	5285	5326	5367	5407	5446	5485	5523	5560
60	5333	5370	5407	5443	5480	5516	5550	5584	5619
65	5413	5446	5480	5513	5546	5578	5610	5641	5671
70	5482	5513	5543	5573	5603	5633	5661	5689	5717
75	5538	5566	5594	5621	5649	5676	5702	5728	5754
80	5579	5606	5632	5657	5683	5708	5733	5757	5781
85	5604	5630	5655	5679	5704	5728	5752	5775	5798
Perpendicular........... 90	5613	5638	5663	5687	5711	5735	5758	5781	5804

NOTE.—The dimensions of the earth are not sufficiently well known to render the sixth place of decimals in the value of log ρ reliable.

APPENDIX No. 19.

HYPSOMETRIC FORMULA BASED UPON THERMODYNAMIC PRINCIPLES.

[MAY 30, 1878.]

The application of the dynamical theory of heat to barometric measurement of heights, though dating back but a few years, appears promising even in its, as yet, restricted use, and the barometric formulæ at present ordinarily employed may possibly in the course of time be superseded by it. As a supplement to the paper Appendix No. 16 of this Report, I have thought that a brief account of the theory and a test of the same, using the reliable data furnished in that Appendix, might be both instructive and of practical value.

Two important papers on the subject have been published by Prof. A. Weilenmann, from the latter of which, entitled "Ueber ein abgeändertes Aneroidbarometer und Beziehung zwischen Luftdruck, Temperatur und Höhe in der Atmosphäre" (Vierteljahrschrift der Schweizer Naturforschenden Gesellschaft, Zürich, 1876), the following account has been prepared:

Let Q represent the total heat contained in a kilogramme of gas, E the dynamical equivalent of a unit of heat or 423.5 expressed in kilogrammetres, and put $A = \frac{1}{E}$; also let T = absolute temperature or -273° for the centigrade scale, c = specific heat of gas at constant pressure, p = total external pressure, v = volume of a unit of weight and R a constant for each particular gas, then the fundamental thermodynamic equations are

$$dQ = c\,dT - A\,R\,T\,\frac{dp}{p} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

$$p\,v = R\,T \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

If dh represents an infinitely small change of height then

$$dh = -\frac{R\,T}{p}\,dp, \text{ hence } d\,Q = c\,dT + A\,dh \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

From these equations Professor Weilenmann deduces the following hypsometric formula:

$$A\,(h_2 - h_1) = c\,T_1\left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{A\,R}{c}} e^{\frac{1}{c}\int\frac{dQ}{T}}\right] + Q_2 - Q_1 \quad . \; . \; . \; . \; . \; . \quad (4)$$

where h_1 and h_2 the heights above the half-tide level of the ocean of two places in the same vertical, p_1 and p_2 the corresponding pressures of the atmosphere, T_1 the absolute temperature of the air at the lower station, and Q_1 and Q_2 the absolute quantity of heat contained in one kilogramme of air at the lower and upper stations respectively.

Under the supposition that on clear days, especially in summer on afternoons, and when no condensation of vapor takes place, the intervening column of air neither loses nor gains heat, the expression (4) changes into the simple form

$$h_2 - h_1 = \frac{c}{A}\,T_1\left(1 - \left(\frac{p_2}{p_1}\right)^{\frac{A\,R}{c}}\right) \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

In Appendix No. 16 of this Report, referred to above, this remarkable constancy of the temperature of the atmospheric column is shown to hold by means of the inversion of the barometric formula.

A and R change slightly with the geographical latitude and with the altitude, A R remaining constant, R and c change slightly with the humidity of the air. These relations are expressed by

$$\left.\begin{aligned} A &= \frac{A_0\,\rho^2}{(1 + \beta\cos 2\,\varphi)\,(\rho + h_1)\,(\rho + h_2)} \\ R &= R_0\,(1 + \beta\cos 2\,\varphi)\,\frac{(\rho + h_1)\,(\rho + h_2)}{\rho^2}\left(1 + 0.378\,\frac{\pi}{p}\right) \\ c &= c_0 + 0.1511\,\frac{\pi}{p} \end{aligned}\right\} \quad . \; . \; . \; . \; . \quad (6)$$

where π = vapor pressure of the air expressed in millimetres of mercurial column, φ = the latitude, ρ = the earth's radius; A_0 and R_0 answer for latitude 45° and for the sea-level. For dry air $c = 0.23751$. For the earth's radius we can take $\rho = 6366200$, also $A_0 = \frac{1}{424}$ and $R_0 = 29.280$ for metric units; $\beta = 0.002626$ according to Bessel.

If b_1 and b_2 are the readings of a mercurial barometer at the lower and upper stations respectively, then

$$\frac{p_1}{p_2} = \frac{b_1 (\rho + h_2)^2}{b_2 (\rho + h_1)^2} \quad \ldots \ldots \quad (7)$$

and for the aneroid readings a_1 and a_2 at the lower and upper stations

$$\frac{p_1}{p_2} = \frac{a_1}{a_2} \quad \ldots \ldots \quad (8)$$

Developing expression (5) into a convergent series it becomes

$$h_2 - h_1 = \mathrm{R}\,\mathrm{T}_1\, l \frac{p_1}{p_2} \left[1 - \frac{1}{2} \frac{\mathrm{A}\,\mathrm{R}}{c}\, l \frac{p_1}{p_2} + \frac{1}{6} \left(\frac{\mathrm{A}\,\mathrm{R}}{c}\right)^2 \left(l \frac{p_1}{p_2}\right)^2 - \ldots\right] \quad \ldots \quad (9)$$

where l is a hyperbolic logarithm.

The first term, or

$$\mathrm{H} = \mathrm{R}\,\mathrm{T}_1\, l \frac{p_1}{p_2} \quad \ldots \ldots \quad (10)$$

which for the mercurial barometer changes into

$$\mathrm{H} = \mathrm{R} \left(1 + \frac{2\,\mathrm{R}\,\mathrm{T}_1}{\rho}\right) \mathrm{M}\,\mathrm{T}_1 \log \frac{b_1}{b_2} \quad \ldots \ldots \quad (14)$$

M being the multiplier for common logarithms or 2.302585

Put

$$\mathrm{S} = \mathrm{R} \left(1 + \frac{2\,\mathrm{R}\,\mathrm{T}_1}{\rho}\right) \mathrm{M}$$

then with sufficient accuracy

$$\mathrm{S} = 29.280\,(1 + \beta \cos 2\,\varphi)\, \frac{(\rho + h_1)\,(\rho + h_2)}{\rho^2} \left(1 + \frac{2 + 29.280\,\mathrm{T}_1}{\rho}\right) \left(1 + 0.378 \frac{\pi}{b}\right) \mathrm{M} \quad . \; . \quad (15)$$

where

$$\frac{\pi}{b} = \frac{1}{2} \left(\frac{\pi_1}{b_1} + \frac{\pi_2}{b_2}\right)$$

hence

$$\mathrm{H} = \mathrm{S}\,\mathrm{T}_1 \log \frac{b_1}{b_2} \quad \ldots \ldots \quad (16)$$

and finally

$$h_2 - h_1 = \mathrm{H} \left[1 - \frac{1}{2} \frac{\mathrm{A}\,\mathrm{H}}{c\,\mathrm{T}_1} + \frac{1}{6} \left(\frac{\mathrm{A}\,\mathrm{H}}{c\,\mathrm{T}_1}\right)^2 - \frac{1}{24} \left(\frac{\mathrm{A}\,\mathrm{H}}{c\,\mathrm{T}_1}\right)^3 + \right. \quad \ldots \ldots \quad (17)$$

and with sufficient accuracy up to differences of height of 4000 metres

$$h_2 - h_1 = \mathrm{H} - \frac{\mathrm{H}}{2} \left(\frac{\mathrm{A}\,\mathrm{H}}{c\,\mathrm{T}_1}\right) + \frac{\mathrm{H}}{6} \left(\frac{\mathrm{A}\,\mathrm{H}}{c\,\mathrm{T}_1}\right)^2 \quad \ldots \ldots \quad (18)$$

The computation is facilitated by tabulation of S_1 or the part of S which is independent of the humidity factor, for various heights h_2 and temperatures T_1.

For ordinary application we have, with sufficient approximation,

$$\log \mathrm{S} = \text{tabular value of } \log \mathrm{S}_1 + 0.000004\, \varDelta\, \mathrm{T} + 0.163 \frac{\pi}{b} \quad \ldots \quad (21)$$

The table for $\mathrm{T}_1 = 275°$ and $h_1 = 500$ is as follows:

h_2	$\phi = 30°$	35°	40°	45°	50°	55°	60°
m.							
0	1.83047	1.83029	1.83010	1.82990	1.82970	1.82951	1.82933
1000	54	36	17	2997	77	58	40
2000	61	43	24	3004	84	65	47
3000	68	50	31	3011	91	72	54
4000	75	57	38	3018	98	78	61

When an aneroid is used, the factor $\frac{2 \times 29.280 \, T_1}{\rho}$ in the expression of S is to be omitted. For the value $\frac{A}{c}$ a rough approximation only is needed, we may put log $\frac{A}{c} = 7.9924 - 10$.

Applied to the case of Bodega Head and Ross Mountain, California, the computed difference of height for the hours 8, 9, 10, 11, noon, 1, 2, 3, 4, 5, are $597^{m}.8$, 601.6, 604.1, 604.5, 604.0, 604.7, 604.2, 603.0, 602.7, 600.3, respectively, the true value by spirit-leveling being $598^{m}.7$. Compared with the best results from the ordinary barometric formula, the differences appear reduced to nearly one-half of the old residuals,* yet the diurnal variation in the results remains strongly expressed.

It would also appear that the new formula gives the true difference of height about 8¼ a. m. and 5½ p. m.

CHAS. A. SCHOTT.

---

* See diagram, page 353 of this Report.

APPENDIX No. 20.

[Reprinted, with additions, from the United States Coast Survey Report for 1871, Appendix No. 15.]

ON THE ADAPTATION OF TRIANGULATIONS TO VARIOUS CONDITIONS, DEPENDING ON THE CONFIGURATION OR OROGRAPHIC CHARACTER OF A COUNTRY AND ON THE DEGREE OF ACCURACY AIMED AT, WITH DUE CONSIDERATION OF THE TIME AND MEANS AVAILABLE; ALSO NOTES ON THE METHOD OF OBSERVING HORIZONTAL ANGLES AND DIRECTIONS IN GEODETIC SURVEYS. BY CHARLES A. SCHOTT, ASSISTANT UNITED STATES COAST AND GEODETIC SURVEY.

Whatever the design of a geodetic operation, whether it be to include and define a portion or the entire surface of a country, or only its coast or boundaries, or whether its purpose be to measure arcs of the meridian, of the parallel, or inclined arcs (as a contribution to the data for ascertaining the figure of the earth), it must in all cases be based upon a triangulation, the greater or less complexity of which will depend chiefly and necessarily on the hypsometric features of the country and on the nature of its surface.

Geodesy may briefly be defined as one of the applied sciences which has for its object the determination of the figure and size of the earth and of determining geographical positions on its surface, usually referred to three co-ordinates, viz, latitude, longitude, and altitude, and which is occupied with problems or relations between such points. It is thus distinguished from ordinary surveying, which excludes astronomical observations and within circumscribed limits regards the geometrical surface of the earth as plane or exceptionally as spherical.

The adaptation of a triangulation to these various conditions, while at the same time paying proper attention to accuracy, economy, and rapidity of execution, requires special considerations in each case. Before discussing these conditions more closely, however, it will be advantageous to refer briefly to the different kinds of triangulation. For the sake of convenience they have been classified under the heads primary, secondary, and tertiary. These may be defined as follows:

Primary triangulation is characterized by the *maximum* development which the configuration of the country admits of. Its sides may frequently exceed 160 kilometers (about 100 statute miles) in length, while they rarely descend below 30 kilometers (about 19 miles) for hilly or slightly undulating surfaces, and never below 20 or 25 kilometers (about 12 or 15 miles) in perfectly level countries. Primary work is executed with the greatest possible accuracy. The uncertainty in its resulting linear measures may be less than about $\frac{1}{100000}$ of the length, and is rarely as great as $\frac{1}{60000}$ (which represents an error of about 1 inch to the mile). To reach a higher standard of excellence, as for instance $\frac{1}{2000000}$, or even a smaller fraction, requires the application of the most refined means at our disposal.

Tertiary triangulation, which should be accommodated to the wants of the topographer and the hydrographer, practically brings its sides down to the minimum length demanded for plane-table work on a large scale (between about $\frac{1}{2500}$ and $\frac{1}{10000}$). They may be as short as $1\frac{1}{2}$ or $2\frac{1}{2}$ kilometers (1 or $1\frac{1}{2}$ miles). Ordinarily, the sides vary between 5 and 8 kilometers (about 3 and 5 miles). In this work an uncertainty of $\frac{1}{5000}$ in the resulting distances is commonly considered a lower limit. $\frac{1}{20000}$ may be taken as upper limit, and $\frac{1}{10000}$ is about an average value.

Secondary, or the intermediate, triangulation simply effects a connection between the above extremes. Its accuracy may commonly range between $\frac{1}{20000}$ and $\frac{1}{50000}$ of the length.

Any one of these classes of triangulation may be formed of a distinct or separate series of combinations of triangles, and the primary class always does so; or the secondary and tertiary may cover the same area as the primary, in which case they are directly checked by it. Any series of triangles (or combinations of triangles) designed to connect two distinct positions, such as opposite boundaries, terminal points of an arc, or separate branches of a triangulation—for instance, those running along a coast or up a river—should be laid out and measured as a *main* or *principal* series, along which *distances* and *azimuths* are carried forward in the most accurate (relatively) and expeditious manner. The termination of such branches is usually strengthened by the measure of a check-base and of an astronomical azimuth.

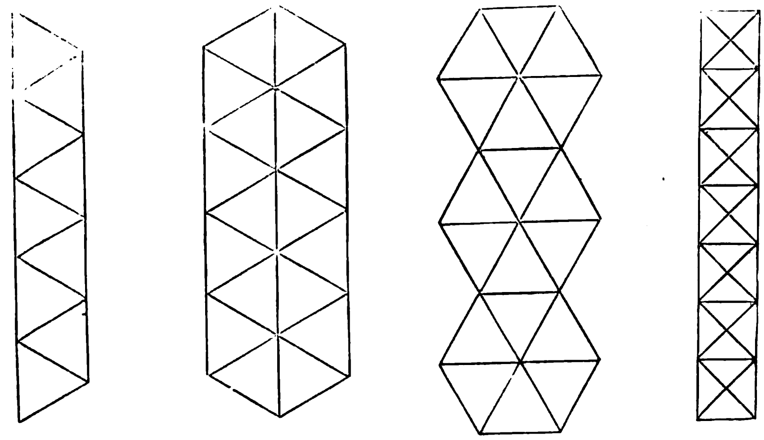
If a country is to be covered with a net-work of triangles (or combination of triangles), the question will arise how to arrange these in the most effective manner. We may, for instance, gradually cover the whole area with contiguous triangles—all measured with equal care—taking advantage of the surface irregularities so as to expand to the greatest scale practicable. This system has the disadvantage of leading rapidly into an unmanageable number of conditions to be satisfied in the adjustment of the parts. This necessitates the parceling out of the net-work into certain connected, yet in a measure arbitrary, figures, not too extensive to be separately adjustable; and requires a further adjustment to remove the discrepancies along the junction or boundary lines of the contiguous figures. On the other hand, we may first surround the surface by a connected series or chain of primary triangulations, to serve as a *frame-work* in which other primary equidistant and parallel *traverse* series may be inserted; and after adjusting this figure* we may introduce a second system of parallel series of subordinate triangulation at right angles to the former in order to cut or subdivide the interjacent (rectangularly-shaped) areas left by the preceding system, and we may continue such subdivision of areas until the whole surface is covered sufficiently with trigonometrical stations. This produces the so-called gridiron system. In adjusting any system, the preceding one upon which it depends is taken as not subject to any further correction. As in the first method, every advantage must be taken of the natural facilities offered by the ground, and sometimes diagonal—or tie—series may be more advantageous than rectangular connections. For the survey of a coast-line or boundary, we may run a main series on more elevated ground parallel to the general direction of the line, and select for it the most suitable ground. Lateral branches at intervals may connect the main series with the coast or boundary. A series of triangles following a mountain range or axis of elevation may advantageously rest with one side on the crest or slope, and with the other on the plane at the foot of the elevation; but the most favorable case of configuration is that of a valley of the proper width in comparison with the relative elevations and a well-shaped triangulation resting on the crest of the ranges or hills on each side. The most difficult ground to traverse for primary triangulation is heavily wooded parallel ridges, closely packed and of nearly equal height, running at right angles to the direction of the triangulation.

The general direction and character of a triangulation having been decided on, we have next to consider its composition. A series may be formed of a single string of triangles, of a double string or hexagons (or of other polygonal figures), of quadrilaterals, or it may be composed of any irregular combination of triangles. Since any of these systems may find its proper application, according to circumstances, a somewhat closer examination of their relative merits seems to be demanded.

The plainest form is that of a single string of equilateral triangles, and is the one to be adopted when economy and rapidity of execution are the first requisites; the hexagons (connected either axially or hinged) commend themselves when a large area is to be covered; and a third form, that of quadrilaterals, offers itself as the one possessing greatest strength or admitting of

* In general, to close any circuit or chain of triangles returning into itself four equations must be satisfied, which may be considered as arising in the following manner: First. The *length* of the connecting side must come out the same, whether we arrive at it by computation from one direction, or from the opposite. Secondly. The resulting *azimuths* of this line must be the same. Thirdly and fourthly. The *latitude* and the *longitude* of one of the end-points of the line, respectively, must show no discrepancy. In the case of primary traverses the circuits are mutually dependent, and require to be treated collectively.

the greatest accuracy. The relative value of the usually mixed systems may be judged from their characteristics when compared with the three simple systems just mentioned.



If we take for the unit of length the maximum distance at which it is advisable to place two stations for observation, in conformity with the nature of the ground, the efficiency of the instruments, and the means at our disposal, we may estimate the relative value of the three systems under various aspects by examining their results for a given equal linear extent. Since nine equilateral triangles, reaching to five units, carry us nearly as far as three hexagons ($3\sqrt{3} = 5.20$ nearly), and slightly surpass seven quadrilaterals, having diagonals of unit-length ($7\sqrt{\frac{1}{2}} = 4.95$ nearly), a length of five may be taken as a convenient measure of comparison for relative value.

The following table exhibits such numbers as are required for comparison:

System.	Composition.	Range.	Number of stations.	Total length of sides.	Area covered.	Number of conditions.
I	Triangles, equilateral	5	11	19	4.5	9
II	Hexagons, hinged	5.2	17	34	9	21
III	Quadrilaterals, squares	4.95	16	29.6	3.5	28

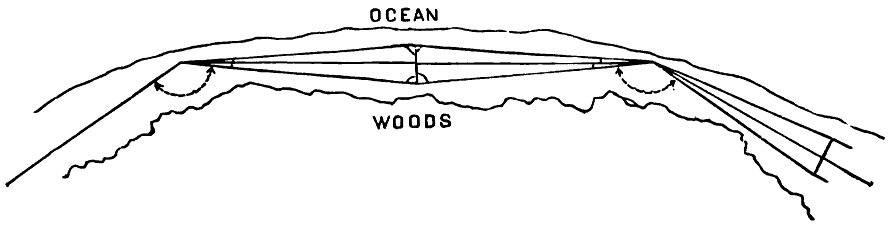
With respect to the *number of stations* to be built up or occupied, system I is the most favorable, and II and III are almost equal; with respect to *length of sides*, of special importance when lines have to be cut through heavy woods or brush, system I is least unfavorable, and system III slightly better than system II; with respect to *area* covered, system II is by far the most advantageous, the other systems showing but one-half and less, than the hexagonal; this system appears, therefore, best adapted when spread of triangulation is most desirable; but if axially arranged, the hexagons are less favorably disposed, being narrower and lacking the salient points of the ordinary connection. With respect to the number of geometrical conditions,* system III is the most favorable, and, with these conditions satisfied, it will be capable of giving the greatest relative accuracy. Strength, however, is here gained at the expense of area. Generally, for compara-

*If in system I, n = number of stations, not less than 3, then number of conditions $= n - 2$; for system II, n = number of stations, not less than 7, and forming complete hexagons, number of conditions $= \frac{7n - 14}{5}$; for system III, n = number of stations, not less than 4, and forming complete quadrilaterals, number of conditions $= 2n - 4$.

† In the measures of directions at a primary station, should a line offer special difficulties from its great length or rom want of transparency of the atmosphere, the expedient may be adopted of erecting a signal at a moderate distance in or nearly in its direction and measuring *micrometrically* the angular difference of the two objects under favorable circumstances. The use of so-called referring objects is not in general recommended, as it unnecessarily increases by one the number of directions to be fixed, unless it be itself one of the trigonometrical stations, namely, the one visible under all observing conditions.

tively flat surfaces, the hexagonal, and for countries traversed by mountain ranges, the quadrilateral system may be employed with advantage; while for rapidity of work and cheapness a string of single triangles is unsurpassed. Yet however complicated, mixed, stretched or distorted the actual scheme may be, we always keep in view that the greatest care is to be given to the measures connected with the main series, while at the same time due attention is given to the secondary objects, thus saving reoccupation of the primary stations in connection with the subordinate work.†

Two other systems of survey may here be noticed designed to meet the special difficulty where want of breadth makes the ordinary methods inapplicable. Their use applies to the case of a narrow sea-beach fringed with woods which it may be undesirable or impracticable to penetrate. The system first to be described, and which has been successfully employed on certain parts of our southern coast, consists in actually measuring a series of connected lines as in base-measures, either with rods or wires, the termini of each line being at the *maximum* distance admitting of intervisibility, and in measuring the angle between the lines or their difference of azimuths at each junction. Each one of such lines may be composed of a number of broken lines, but the parts are referred to the single straight line at the termination of which angles are measured. Owing to the expense and delay of line measures the application of this method is limited. In the second auxiliary method, due to Struve,* these objections are met by the substitution of a number of small base-lines—that is, one for each long line—and located so as to be at right angles and bisect each other as nearly as may be, thus forming a se es of greatly drawn-out quadrilaterals. The horizontal angles are then measured at the ends of e little base, also at the terminal points of the long line, the length of which thus becomes known. The base may be from one hundred to several hundred meters in length, and that of the long line or diagonal may be from ten to fifteen times that of the base. Azimuthal differences are measured as before, and the computation of the latitude and longitude of the points is effected as in ordinary triangulation. This last expedient may be of occasional assistance when operating on shores obstructed by water-courses, lagoons, or swamps. Islands or rocks, lying off shore at no great distance, frequently supply the means of carrying a subordinate series of triangulation along shore.



The following remarks on the length of primary base-lines, and on their distances apart, may find a proper place at the conclusion of this paper: In the present state of practical geodesy, primary base-lines of a length of about 10 or 11 kilometers (nearly 6½ statute miles) represent a fair average.† The intervening primary triangulation varies greatly in extent. This depends principally on the size of the triangles and on the accuracy of the measures; yet ordinarily any two primary base-lines may be found separated by a distance from fifty to eighty or even one hundred times the average length of a base; that is, from about 500 to 1000 kilometers (about 300 to 600 miles). Tertiary base-lines are usually between ¾ and 2½ kilometers (about ½ and 1½ statute miles) in length, and in a chain of tertiary triangulation not otherwise checked they may follow at intervals of about 40 or 70 kilometers (nearly 25 or 44 miles), or at distances about 25 times their length. Secondary base-lines are usually from 3 to 5 kilometers in length (about 2 to 3 statute miles), and the distance between two such base-lines should not exceed 50 times their length. It will be well to expand gradually the length of sides from the base, about doubling or tripling the sides at each step until the desired average length of the primary side is reached.

* Astronomische Nachrichten, No. 336 (1837).

† Thirteen lines of the Coast Survey average 6.2 statute miles; ten of the Indian trigonometrical survey, 6.6; and seven of the English ordnance survey, 5.9 miles.

The properties of a base-line, or, more strictly, of its theoretical equivalent, have been but little investigated, and a few remarks respecting its definition may not here be deemed out of place.

A base-measure may be conceived to proceed from the starting point A, on the surface of a spheroid, in a plane containing both its vertical and the terminal point B, and to be continued so that at any point of it, its linear element is situated in the plane passing through its normal and through the termini A and B. A curve so traced will in general be of double curvature, and lie between (excepting the case when A and B are on the same parallel) the two plane elliptical arcs *a* and *b*, which result, the first from the intersection of the spheroid by the vertical plane containing the normal of A and the point B, the second from the intersection of the plane containing the normal of B and the point A. The element of the curve at A will necessarily coincide with the arc *a*, and at B with the arc *b*, and the curve will be similarly related to these arcs; that is, the same curve will be traced out whether we start from A toward B or from B toward A. It has, from its definition, the property that for any point in it the forward and backward azimuths differ 180°; and since the terminal points A and B lie in the plane of its normal, the azimuthal plane must contain the chord or straight line joining A and B. The curve will also be marked out by the junction of the foot-points of normals let fall from every point of the chord to the surface of the spheroid. The curve, being situated apparently in a direct line between the terminal points, may be distinguished by the name "direction-line," the name base-line having been given to the line actually measured, and which is composed of a number of straight lines, each of the length of the measuring apparatus. Dr. Bremiker* pertinently remarks that the name "geodetic line" should properly have been given to this curve, since it actually enters directly into the two fundamental geodetic operations, viz: the linear and angular measures; the latter on account of the tangency of the curve to the plane of the arc *a* in which the line of collimation of a theodolite stationed at A is situated. The name "geodetic line," however, is already appropriated for the shortest line (and which does not always lie between the arcs *a* and *b*) that can be drawn between two points on the surface of the spheroid, and which also differs in direction from the curve here considered.

NOTES ON THE METHOD OF OBSERVING HORIZONTAL ANGLES OR DIRECTIONS IN GEODETIC SURVEYS.

It is here proposed to review briefly the methods followed in taking angular horizontal measures at trigonometrical stations.

The angular measures made in the older trigonometrical surveys generally extended only to those particular angles which actually formed part of the triangles, thus involving the minimum expenditure of labor. The method of measuring angles by application of the principle of repetition, first proposed by T. Mayer, sr., in 1752, and introduced a few years later (1755) into astronomical and geodetic practice by Borda, was a marked improvement in all cases where instruments had to be employed whose weakest part was their graduation. This method, though still followed in cases when the instrumental means available recommend it favorably, is being gradually superseded by the method of observing directions in series. This change is mostly due to great improvements in the construction of the mechanical and optical parts of theodolites, more especially to the superior accuracy of the graduation of the circle and the introduction of micrometer microscopes.

The method of observing in series is specially referred to by Gauss (in Astronomische Nachrichten, No. 6, 1822) and by Bessel in his practical work "Die Gradmessung in Ostpreussen," etc., Berlin, 1838, where the method is more fully developed.

The same method of observing was adopted by Struve, in 1823 (see Ast. Nach., No. 47), in consequence of the method of repetition used by him in the preceding year proving unsatisfactory. He remarks as an important advantage of the new method, which determines for every object the position on the fixed azimuth circle of the vertical plane passing through it and the object observed, that the angular distances (combining the directions two by two) of the objects become known with equal accuracy.

* Studien über höhere Geodäsie, Berlin, 1869. The name "field-line" is suggested by Dr. Bremiker, who gives the equation to the curve on page 66 of his pamphlet.

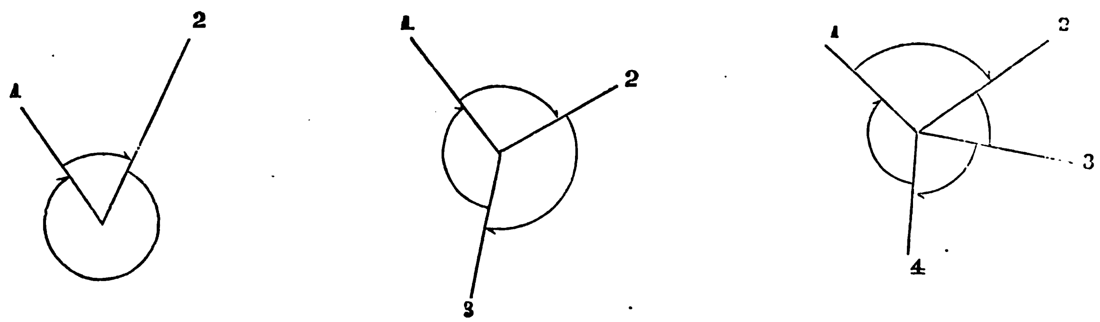
An angle may be considered as formed by the difference of two directions, and let μ equal the probable error of a direction. Suppose there are three objects to be observed at a station and the angles measured between the first and second, also between the second and third, then each angle would be subject to the probable error $\mu\sqrt{2}$, but the angle between objects two and three would be affected with a probable error of 2μ. If, however, the three objects had been observed in series, the probable error of any one of the angles would only be $\mu\sqrt{2}$; moreover, the labor involved would only be 3 in comparison to 4 as in the method of observing angles. Thus, in general, it will be more advantageous to observe in series.

Both methods of observing have been used in the Coast Survey and are still in use, according to the character of the work and the construction of the instruments. In 1817, Superintendent Hassler used the twenty-four inch Troughton theodolite, the circle being placed generally in three positions 120° apart, when observing in series; in this he has been followed by his successors in office, who to insure greater accuracy have increased the number of positions and series. The method of series is now almost exclusively followed in the more refined geodetic operations as in primary triangulations.

Using either method, a complete observation will include or is composed of two measures; one with telescope direct, the other with telescope reversed (alidade turned 180°, and telescope reversed about its axis of support, without changing pivots or Y's), in order to eliminate any defect arising from imperfect collimation from inequality of height of Y's, and irregularity in form of pivots. In case the Y's are too short to permit the complete turning of the telescope, the latter must be lifted off its Y's and, after reversal, carefully replaced, the same pivot resting on the same Y as before. Experience has shown that the use of repetition is not unfrequently accompanied by the introduction of constant errors; whether this arises from the effect of drag, of imperfect construction of clamping apparatus, or from other causes, is immaterial so long as they exist. In fact, the high expectations entertained for the principle of repetition were not realized, and it was evident that certain small errors were simply repeated instead of being eliminated.

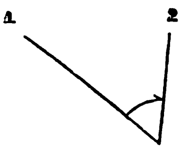
Under all circumstances, however, it was desirable to introduce certain conditions or checks, such as the measure of all the angles around the horizon, known as the closing of the horizon, or the measure of whole arcs together with their parts or so-called summation-angles.

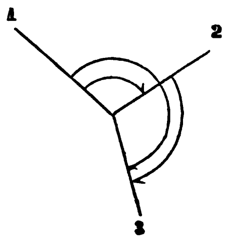
In No. 2117 of the Astronomische Nachrichten, Dr. Bremiker mentions as the older method of measures of angles, one practiced in the measurement of the French arc, also adopted in German surveys by General Müffling and by other geodesists, which consists in measuring separately and successively every angle formed by two adjacent directions including the first again, thus closing the horizon as shown in the figures.

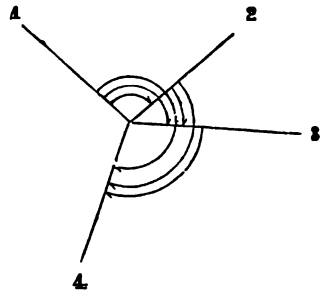


There is therefore but one condition between the measures, no matter what the number of directions at a station may be.

In the survey of Hanover, Gauss employed (according to Dr. Bremiker's article above cited) a method of measuring independently every angle subsisting between every direction and every other one, as shown in the figures.





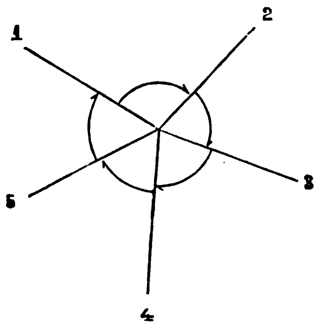


Angles measured:			
	1–2	1–2	1–2
		1–3	1–3
		2–3	1–4
			2–3
			2–4
			3–4

The number of conditions for 2, 3, 4, 5, etc., directions at a station are 0, 1, 3, 6, 10, etc., respectively.

Supposing, now, that angles are to be measured by repetition, the following scheme may be proposed which the observer may keep in mind, and to which he may adhere as closely as circumstances of time, weather, and expense may permit him to do. Supposing, for instance, the number of primary directions at a station to be 5 (and the process described will be similar for any other number), we first take the indispensable measure of each single angle, inclusive of closing the horizon:

Namely the angles
1–2
2–3
3–4
4–5
5–1



To increase the accuracy of the result, we next measure all the combinations by twos, viz, the angles—

1–3
2–4
3–5
4–1
5–2

We will further increase the accuracy by measuring the combinations of threes, viz:

1–4
2–5
3–1
4–2
5–3

And, finally, we may measure the last combinations by fours, viz:

1–5
2–1
3–2
4–3
5–4

This will insure the closing of the horizon in several ways as well as the combination of measures known as summation-angles. Differently arranged these angles are—

1–2	2–3	3–4	4–5	(5–1)
1–3	2–4	3–5	(4–1)	(5–2)
1–4	2–5	(3–1)	(4–2)	(5–3)
1–5	(2–1)	(3–2)	(4–3)	(5–4)

where the angles inclosed in parentheses are those not included in the method first mentioned. If we stop observing after the third combination, the five angles given in the last line would remain unmeasured. Stopping short at the preceding combination, the angles in the last two lines would have no existence and the accuracy of our results would be proportionally diminished.

For the modern precise measures we employ in preference instruments whose well-graduated azimuthal circle is firmly supported, and is without any clamp or tangent-screw attachment, its graduations being simply viewed through (generally) three micrometer-reading microscopes. This circle, however, can be changed in position either by means of a revolving stand or by turning the circle itself in its collar, where it is held by slight friction, so as to bring other parts of the graduation successively into use. These positions may be said to take the place of the repetitions of the other method. The number of positions should be a prime number, generally selected from the numbers 3, 5, 7, 11, 13, 17, 19, 23, etc., a smaller number for the better graduated circles and a larger one for inferior ones.

For these more refined measures Bessel's method of observing directions or so-called arcs or series is generally followed. Thus, for any one position of the circle a number of such series are made, each consisting of successive pointings and readings of all the (observable) signals in the order of the graduation of the circle, and after the reading of the last direction in reversing the telescope (the readings now differ very nearly 180° from the corresponding ones first made) and observing each signal again simply in the reverse order, ending with the first direction.

We shall thus obtain a series of readings of the directions 1 2 3 4 5, followed by 5 4 3 2 1, the circle and telescope having been reversed.

The mean is taken for each direction as the result of the series. From any complete series one or more directions may occasionally be wanting by reason of unsteadiness or invisibility, and we may begin the measures with any one we choose. Thus we may have directions 2 3 4 5 or 1 2 5 or 2 5, etc., etc.

Instead of arranging observations in this way, we may change the scheme by shifting the first object in each new series so as to carry the alidade necessarily over every part of the circle. Thus, for any one position and, say, five directions, we would have to observe—

1	2	3	4	5				
	2	3	4	5	1			
		3	4	5	1	2		
			4	5	1	2	3	
				5	1	2	3	4

each series with telescope D and R. After this we would shift the circle to a new position, and so continue the series, their total number depending on the degree of accuracy desired.

Should the number of directions be so great as to render it doubtful whether the circle would remain undisturbed in position (sometimes on isolated hills and on high posts a regular turning of the support in azimuth is observable depending on the period of insolation) the breaking up of the series into two may be performed by omitting one or more directions in each series, different, however, in successive series, as, for instance—

1	2	3					
	2	3	4				
		3	4	5			
			4	5	6		
				5	6	1	
					6	1	2

or

1	2	3	4	5						
	2	3	4	5	6					
		3	4	5	6	7				
			4	5	6	7	1			
				5	6	7	1	2		
					6	7	1	2	3	
						7	1	2	3	4

or

1	2	3	4						
		3	4	5	6				
				5	6	7	8		
						7	8	1	2

each direction being still observed an equal number of times. The principle of symmetry in combination is adhered to both in the method proposed for the measures of angles and for that of directions, in order to have, as near as may be, equal probable errors to the resulting angles or directions.

In order that no time or accuracy may be lost in the measures of the primary directions, the secondary objects should be observed by themselves, as occasion offers, care being taken to connect them with one or more primary directions.

The computer may select any one direction for his initial or zero (or 360°) direction. Should the observer have selected one of the directions as a referring direction (as has been done in the Ordnance Survey of Great Britain since 1840) by reason of its general visibility or superior steadiness, this direction would appear in every series, and in secondary work would materially assist in diminishing labor when deducing the results by an approximate method. A special referring mark not otherwise connected with the triangulation would become necessary in the not unfrequently occurring case when, by reason of great distances, the signals were never simultaneously visible, and a mark may be established if equality in the probable error of each direction is desired.

While it is not expected, and as a rule is even considered impracticable, to have a completely systematic record of angular measures at any one station of the form proposed, the preceding remarks will have served the purpose for which they were intended, by directing the observer's attention to advantageous methods of procedure. The computer will, of course, apply the method of least squares for the deduction of the most probable results from these measures in accordance with the particular system of observing which may have been followed.

APPENDIX No. 21.

ON A CHART OF THE MAGNETIC DECLINATION IN THE UNITED STATES, CONSTRUCTED BY J. E. HILGARD, ASSISTANT UNITED STATES COAST AND GEODETIC SURVEY.

UNITED STATES COAST AND GEODETIC SURVEY OFFICE,
Washington, D. C., July 1, 1879.

SIR: I submit to you herewith, for publication in the Coast Survey Report for 1876, if deemed proper, a chart of the magnetic variation in the United States. This chart, which shows the lines of equal magnetic declination (so-called Isogonic lines) for the year 1875, is mainly based upon the observations made during the progress of the coast survey up to 1877, and those made under my direction during the period 1872–'77, at the charge of the fund bequeathed for scientific research by the late Prof. Alexander Dallas Bache, held in trust by the National Academy of Sciences.

When the income of this fund became available for its objects, I proposed, in 1871, to the board of direction, then consisting of Professors Joseph Henry, Louis Agassiz, and Benjamin Peirce, that a portion of it should be devoted to the investigation of terrestrial magnetism in the United States, that subject being one in which Professor Bache had taken much interest, and in the investigation of which he had been personally engaged. Moreover, while this was a subject of general importance, there was not at that time any provision made for its prosecution on the part of the government. The board of direction having approved of my proposition, an allotment was made for several years in succession, and the observations were prosecuted under my immediate direction by observers whom I personally instructed in the work. In this way observations of the magnetic declination were made at 250 stations, distributed over a very large area of the interior country, at 180 of which stations the dip and horizontal intensity were also observed. These observations will be published in detail under the auspices of the National Academy of Sciences.

Subsequently, when on the extension of the scope of the Coast Survey so as to embrace the interior country, you proposed to undertake the requisite magnetic observations, the board of direction of the Bache fund deemed it best to close the work that I had been carrying on, and to publish the results obtained in the most available form, beside printing the observations themselves as a matter of record. Such publication can best be effected by combining them with all similar data available, and giving a graphic representation of the general result.

In the accompanying map (Illustration No. 24), this has been done for the declination (or variation of the compass) which is the element of the most practical utility. Since the data obtained by the Coast Survey form a very large part of the material used, an early publication in the Coast Survey Report is thought to be the most advantageous mode of giving the results to the country.

The incessant demands made upon the office of the Coast and Geodetic Survey for information relative to the variation of the compass in different parts of the United States bear evidence of the appreciation in which is held the similar map given in the Coast Survey Report for 1865 and published in 1867. The present map cannot fail to meet acceptably the constantly-increasing demand, as it is not only brought up to a more recent date, but is based upon a very much greater number of original observations in the interior.

In its construction I have made use of all available data up to 1877, including, notably, beside the two principal sources already mentioned, the magnetic observations made in connection with the surveys of the Great Lakes and of the Northern and the Northwestern Boundaries by the United States Engineers, and those made under the direction of the General Land Office in tracing some of the principal meridians and base-lines for the surveys of the public lands and the boundaries o some of the Territories. Moreover, some very valuable observations have been furnished by private observers, which will be specified in another place.

It was fortunate that, for the construction of this chart, the researches of my colleague, Assistant Charles A. Schott, on the secular variation of the magnetic declination in the United States were available, without which it would have been difficult to reduce the observations to a common date, with some approach to accuracy. His latest paper on this subject, printed recently, will be found very useful for reference.

For a separate publication, it will probably be convenient to print Mr. Schott's map, illustrating the annual change, on the obverse side of the chart of magnetic declination, in order to make the sheet available for use without the aid of an explanatory text.

I am indebted to Mr. A. Lindenkohl, chief draughtsman in the Coast and Geodetic Survey Office, for his valuable aid in the graphic construction of the Isogonic lines.

Very respectfully,

J. E. HILGARD,
Assistant Coast and Geodetic Survey.

CARLILE P. PATTERSON, *Superintendent.*

APPENDIX No. 22.

A STATEMENT CONCERNING THE RELATION OF THE LAWFUL STANDARDS OF MEASURE OF THE UNITED STATES TO THOSE OF GREAT BRITAIN AND FRANCE. BY J. E. HILGARD, ASSISTANT UNITED STATES COAST AND GEODETIC SURVEY.

UNITED STATES COAST AND GEODETIC SURVEY OFFICE,
Washington, D. C., July 8, 1879.

SIR: I submit the following statement in relation to the American, British, and French standards of measure, conceived in a brief and categorical form, in order to explain statements heretofore made from this office, as well as to give trustworthy data for books of instruction.

It is desirable, for the sake of perspicuity, that the following principal statements should be made:

1st. There is no difference between the standards of weight of Great Britain and those of the United States.

2d. The standards of volume in the United States are the same as those lawful in Great Britain prior to 1826.

3d. There is no difference between the standards of length of Great Britain and those of the United States.

4th. The relation of the American and British standards to the French metric standards is not determined with extreme precision, but the legal enactments [see Annex 1] will suffice for all purposes, except those of great scientific accuracy.

MEASURE OF WEIGHT.

In regard to the standards of measure in customary use in the United States, it should be observed that they have been inherited by our ancestors from England together with the common law. No enactment by Congress has ever been made declaring particular measures in the keeping of the government as standards, except the standard troy pound of the Mint of the United States at Philadelphia, which is an exact copy of the Imperial troy pound of Great Britain procured in 1827.

Elaborate comparisons, made at various times from the year 1855 up to the present date, of this *troy* pound, containing 5,760 grains, and of the commercial or *avoirdupois* pound, containing 7,000 grains, derived from the former, with copies of similar weights derived from the standard pound of Great Britain, have shown that there is not so much as one-thousandth of a grain outstanding between the money-standards of the two countries.

MEASURE OF CAPACITY.

Of the measures of capacity, which are not measures of great precision, it is only necessary to say, that the old British wine-gallon of 231 cubic inches, and the old Winchester bushel, containing 2,150.5 cubic inches, are the recognized standards in the United States, as they were the lawful standards before the separation of the colonies from Great Britain, no subsequent enactment having been made.

MEASURE OF LENGTH.

The measure of length, which is the yard of 36 inches, is legally in the same condition as the measures of capacity. The standard yard of Great Britain was lawful in the colonies before 1776. By the Constitution of the United States the Congress is charged with fixing the standard of weights and measures (Art. I, sec. 8); but no such enactment has ever been made by Congress, and therefore that yard which was standard in England previous to 1776 remains the standard

yard of the United States to this day—the same being also true of the commercial or "avoirdupois" pound, and of the gallon and bushel, as above stated.

It must not be supposed that this is a matter which, in view of the great questions of public policy engrossing the attention of Congress in early years, had remained without due consideration. The journals of both houses of Congress show that committees were early appointed for the consideration of the subject. A Senate committee reported on March 1, 1791, that "it would not be eligible at present to introduce any alteration in the measures and weights which are now used in the United States." Other reports were made from time to time, and in January, 1820, a committee of the House of Representatives presented their conclusions, which were: "That little should be done; that standards conformed to those in most common use among us should be accurately made and carefully preserved at the seat of government; that correct models should be placed in different districts of the country; and that the proportions and relations between these should be ascertained."

Again, on March 11, 1822, a committee report was submitted to the same body, making recommendations for rendering "uniform and stable the measures and weights which we at present possess."

Thus after full consideration for thirty years, it was agreed that the matter was in a satisfactory shape, in virtue of our inheritance and traditions, and that no legislation was advisable.

Finally, in 1836, an act was passed directing the Secretary of the Treasury to cause copies of the weights and measures adopted by the Department as standards, for the use of custom-houses, to be supplied to each State, "to the end that a uniform standard of weights and measures may be established throughout the United States." The standards so "adopted" were those of Great Britain, as before described.

The actual standard of length used was a bronze scale of 82 inches, subdivided on silver to tenths of inches, which had been prepared for the Coast Survey of the United States by Troughton, of London. The 36 inches comprised between the 27th and 63d inches, found equal to the average of the whole scale, were taken as the standard yard, and the temperature at which this was considered to be a standard, that is to say, equal to the British Standard Yard, was presumed to be 62° Fahr. It had, however, never been directly compared with that standard, but was simply copied from Troughton's own scale without subsequent verification.

In England, the old standard yard, known as Bird's Standard of 1760, had in the mean time been found to be inadequate in definition for the increasing requirements of science, and a new set of standards of length, weight, and capacity was constructed between 1816 and 1826 of such finished workmanship and precise definition as was required by the science of the time, and every effort was made to reproduce, with the greatest possible exactness, the old standard pound and yard.

Not long after this important work had been accomplished, the standards so constructed were destroyed by the burning of the Parliament buildings in 1834. They have since been reproduced by reference to all of the former accredited standards with which they had been originally compared, and are now known as the "Imperial Standards." Some fifty copies of these standards were constructed and intercompared, and certain of these have been sent to the United States. The avoirdupois pound of 7,000 grains is found to agree within one-thousandth of a grain with the avoirdupois pound of the United States, derived from the Mint-pound heretofore mentioned—an agreement which leaves no question outstanding as to the identity of the units of weight of Great Britain and the United States.

The comparison of the Troughton scale heretofore mentioned with the Bronze Standard Yard No. 11, received from Great Britain in 1856, shows the former to be longer by nearly one-thousandth of an inch in the yard, or, more precisely, 0.00085 inch. By very recent comparisons, however, made by myself at the British Standards Office between the standard Imperial yard and Bronze No. 11, the latter was found to be 0.000088 inch shorter than the former, which may be stated in the form that it is of standard length at a temperature of 62°.25 Fahr. Hence we infer that at 62° the Troughton scale is too long by 0.00076 inch, or that it is standard at 59.8 Fahr., instead of 62° as formerly assumed; and this correction will apply to all measures that have been derived from it. This change, although sensible in operations of extreme scientific precision, is really of no consequence in ordinary practice, as it amounts only to the 1:45,000th part of the whole length—a degree

of accuracy which is seldom required. The correction does not exceed the thickness of one of the lines that define the yards supplied to the States.

Extreme accuracy in this matter is beset with great difficulties, for in addition to that of ascertaining for each particular bar the rate of dilatation by temperature, there is an uncertainty in regard to permanence in the length of the bars themselves. Of the two standard yards presented to the United States, one is of bronze (No. 11), and the other of Low-Moor wrought iron (No. 57). These are found to have changed their relative length by 0.00025 inch in twenty-five years; the bronze bar being now relatively shorter by that amount. This subject is undergoing further investigation.

RELATION OF YARD TO METRE.

Statements in regard to this relation have varied excessively, comparison between the two standards being subject to two great difficulties: first, their different nature and definition, and second, their incommensurability in length. The metre is a platinum bar, cut to length (an *end-measure*), and standard at the temperature of melting ice (32° Fahr.). The length of the yard is defined by lines drawn on a bronze bar, standard at a temperature of 62° Fahr. The difficulty of making accurate comparisons of lengths so differently defined is at once apparent; moreover, as their relative length is such that the metre is something longer than 39.37 inches, it is necessary first to derive the latter length from the yard of 36 inches by minute subdivision into a scale of equal parts, and the addition of the odd amount, a process which involves so many successive operations that the probable error of the result is largely increased by an accumulation of uncertainties.

From these circumstances have arisen the differences in statements of the length of a metre expressed in inches. One of the earliest trustworthy comparisons was that made by Kater, giving the value, generally quoted, of 39.37079 inches. This comparison was made with one of the earlier British standards. A more recent determination is that made by Clarke, at office of the British Ordnance Survey, between a number of the new British standards and several well-accredited copies of the metre, which give, very accordantly, a value of 39.37043 inches. It appears that in the latter observations the coefficients of expansion of the bars used were more accurately ascertained than in the former, and as between these two values the latter probably deserves the preference.

It must be observed, that since both yard and metre are material things, no legislative declaration in regard to their relative value can have any force other than to define what shall be considered lawful equivalents. This circumstance being recognized, when the metric standards were made optional in the United States, Congress, instead of stating the equivalents with excessive minuteness, as was done in Great Britain, merely defined the relation which shall be held lawful, to a degree of precision sufficient for practical purposes; thus we find in the table annexed that the lawful equivalent of a metre is 39.37 inches.

In the United States, Professor Hassler, first Superintendent of the Coast Survey, made very careful comparisons between one of the original iron metres and the Troughton 82-inch scale. The records of his experiments are not now extant, having been destroyed by fire in 1843, but he has published his results, viz: One metre = 39.38092 inches of the bronze yard, reduced to 32° Fahr. He made use of a coefficient of expansion resulting from some experiments made by himself upon a brass wire, which value is much too large; but we cannot now correct his reduction, because we do not know the actual temperatures of comparison. Using Mr. Hassler's rate of expansion, viz, 0.0003783 inch in one yard, for 1° Fahr., and reducing his result to the standard temperature of the yard (62° Fahr.), his successor, Professor Bache, found the value of the metre to be 39.36851 inches of the Troughton scale, then the only accredited standard in our possession. When, however, we apply to the latter the correction of 0.00076 inch in a yard, found as above stated, and ascribe to it the rate of expansion of other bronze alloys—for instance, that found by Airy, from Sheepshank's observations, for the bronze of which the new Imperial standards are made, viz: .000342 inch per yard—we find one metre = 39.37054 inches, as follows:

Hassler's value of metre, reduced to 62°	39.36851
Correction for difference in rate of expansion	+ 0.00119
Correction for excess of Troughton scale in one metre	+ 0.00084
Hassler's comparisons, corrected reduction	39.37054

a value which differs very little from that obtained by Clarke, although it cannot be claimed to possess the same degree of trustworthiness. In fact, if we substitute in the above reduction the rate of expansion for the bronze of the British standards recently determined by Fizeau, viz, 0.000351 inch per yard, we shall get 39.37023.

The value 39.3685 inches, derived as above mentioned from Mr. Hassler's comparisons, was used in the Coast Survey for stating the equivalents in yards of distances known in metres, and it has been so employed, as stated in the respective places, in various lists of geographical positions and tables for projections in the Coast Survey Reports, from 1851 to 1868. Since that time it has been deemed advisable to employ the value obtained by Clarke, viz, 39.3704 inches. The conversion is readily made with very sufficient accuracy, by increasing the distances in yards by their 1:20 000th part. A table of equivalents is given below (Annex II).

It is not practicable to attain greater precision in comparison until after the completion of the new international metres now in course of construction at the International Bureau of Weights and Measures in Paris. When the construction of these shall have been perfected, and when they shall have been thoroughly intercompared, it will be useful once more to attempt to arrive at a closer comparison of the yard and metre than we now possess.

In order to make such a comparison with the least number of successive operations, I have devised the following scheme: Divide a yard into four parts by successive bisections; dividing again the sum of three of these parts into eight equal parts by successive bisections, one of these eighths added to the yard will give the length of the metre with a degree of precision readily within the reach of the comparator; that is to say, the length will be 39.375 inches. Two bars correspondingly divided have been prepared for this purpose, and intercomparison is in progress.

Very respectfully,

J. E. HILGARD,
Assistant Coast and Geodetic Survey
in charge of Verification of Standards.

To CARLILE P. PATTERSON,
Superintendent.

ANNEX I.

An act to authorize the use of the metric system of weights and measures.

Be it enacted by the Senate and House of Representatives of the United States in Congress assembled, That from and after the passage of this act it shall be lawful throughout the United States of America to employ the weights and measures of the metric system, and no contract or dealing, or pleading in any court, shall be deemed invalid or liable to objection because the weights or measures expressed or referred to therein are weights or measures of the metric system.

SEC. 2. *And be it further enacted*, That the tables in the schedule heretofore annexed shall be recognized in the construction of contracts, and in all legal proceedings, as establishing, in terms of the weights and measures now in use in the United States, the equivalents of the weights and measures expressed therein in terms of the metric system; and said tables may be lawfully used for computing, determining, and expressing in customary weights and measures the weights and measures of the metric system.

Measures of length.

Metric denominations and values.		Equivalents in denominations in use.
Myriameter	10,000 meters.	6.2137 miles.
Kilometer	1,000 meters.	0.62137 mile, or 3 280 feet 10 inches.
Hectometer	100 meters.	328 feet 1 inch.
Dekameter	10 meters.	393.7 inches.
Meter	1 meter.	39.37 inches.
Decimeter	1-10 of a meter.	3.937 inches.
Centimeter	1-100 of a meter.	0.3937 inch.
Millimeter	1-1000 of a meter.	0.0394 inch.

Measures of surface.

Metric denominations and values.		Equivalents in denominations in use.
Hectare	10 000 square meters.	2.471 acres.
Are	100 square meters.	119.6 square yards.
Centare	1 square meter.	1 550 square inches.

Measures of capacity.

Metric denominations and values.			Equivalents in denominations in use.	
Names.	Number of liters.	Cubic measure.	Dry measure.	Liquid or wine measure.
Kiloliter or stere	1 000	1 cubic meter	1 308 cubic yards	264.17 gallons.
Hectoliter	100	1-10 of a cubic meter	2 bush. and 3.35 pecks	26.417 gallons.
Dekaliter	10	10 cubic decimeters	9.08 quarts	2.6417 gallons.
Liter	1	1 cubic decimeter	0.908 quart	1.0567 quarts.
Deciliter	1-10	1-10 of a cubic decimeter	6.1022 cubic inches	0.845 gill.
Centiliter	1-100	10 cubic centimeters	0.6102 cubic inch	0.338 fluid ounce.
Milliliter	1-1000	1 cubic centimeter	0.061 cubic inch	0.27 fluid dram.

Weights.

Metric denominations and values.			Equivalents in denominations in use.
Names.	Number of grams.	Weight of what quantity of water at maximum density.	Avoirdupois weight.
Millier or tonneau	1 000 000	1 cubic meter	2204.6 pounds.
Quintal	100 000	1 hectoliter	220.46 pounds.
Myriagram	10 000	10 liters	22.046 pounds.
Kilogram or kilo	1 000	1 liter	2.2046 pounds.
Hectogram	100	1 deciliter	3.5274 ounces.
Dekagram	10	10 cubic centimeter	0.3527 ounce.
Gram	1	1 cubic centimeter	15.432 grains.
Decigram	1-10	1-10 of a cubic centimeter	1.5432 grains.
Centigram	1-100	10 cubic millimeters	0.1543 grain.
Milligram	1-1000	1 cubic millimeter	0.0154 grain.

Approved July 27, 1866.

ANNEX II.

COMPARISON OF YARDS AND METRES.

1 metre = 1.093623 yard = 39.37043 inches.

Metres.	Yards.	Yards.	Metres.
1	1. 093623	1	0. 914392
2	2. 187246	2	1. 828784
3	3. 280869	3	2. 743175
4	4. 374492	4	3. 657567
5	5. 468116	5	4. 571959
6	6. 561739	6	5. 486351
7	7. 655362	7	6. 400743
8	8. 748985	8	7. 315134
9	9. 842608	9	8. 229526

APPENDIX No. 23.

LIST OF PUBLICATIONS RELATING TO THE DEEP-SEA INVESTIGATIONS CARRIED ON IN THE VICINITY OF THE COASTS OF THE UNITED STATES UNDER THE AUSPICES OF THE COAST SURVEY.

The following list of publications relating to the character of the bottom and the Fauna of the sea, in the vicinity of the coasts of the United States, under the auspices of the Coast Survey, has been prepared by L. F. Pourtalès, late an Assistant in the Coast Survey. In the beginning, the investigations were mainly restricted to microscopical examinations of the specimens of bottom brought up by the sounding-lead, and the aim was originally to find therein aids to navigation. Later on, the dredge was brought into requisition, and the greatly increased amount of material was worked up and published at the expense or under the direction of the Museum of Comparative Zoölogy.

1850. On the Distribution of Foraminifera on the Coast of New Jersey, as shown by the off-shore Soundings of the Coast Survey. By L. F. Pourtalès, Assistant Coast Survey, Proc. Amer. Assoc. for Adv. of Sc., Charleston Meeting, 1850.

1850. On the Order of Succession of Parts in Foraminifera. By L. F. Pourtalès, Assistant Coast Survey. Proc. Amer. Assoc. for Adv. of Sc., Charleston Meeting, 1850. Also Amer. Journ. of Sc. and Arts., 2d series. Vol. II. 1851.

1851. Extracts from the report of Professor L. Agassiz to the Superintendent of the Coast Survey on the Examination of the Florida Reefs, Keys, and Coast.* Coast Survey Report for 1851, and reprinted in Coast Survey Report for 1866.

1851. Microscopical Examination of Soundings made by the United States Coast Survey off the Atlantic Coast of the United States. By Professor J. W. Bailey. Smithsonian Contributions to Knowledge, Vol. II.

1853. Letter of the Superintendent to the Secretary of the Treasury reporting the Discovery by Lieutenants-Commanding Craven and Maffitt, of a Bank east of the Gulf Stream. Coast Survey Report for 1853. Also noticed in Proc. Amer. Assoc. for Adv. of Sc., Cleveland Meeting, 1853.

1853. Extract from Letters of L. F. Pourtalès, Assistant in the Coast Survey, to the Superintendent upon the Examination of Specimens of Bottom obtained in the Exploration of the Gulf Stream by Lieutenants-Commanding T. A. M. Craven and J. N. Maffitt, U. S. N. Coast Survey Report for 1853, and Proc. Amer. Assoc. for Adv. of Sc., Cleveland Meeting, 1853.

1854. Specimen Box for Deep-Sea Bottoms, by Lieutenant-Commanding T. A. M. Craven, U. S. N. Coast Survey Report for 1854.

1855. Instrument for procuring Specimens of Bottom in Sounding, by Lieutenant-Commanding B. F. Sands, U. S. N. Coast Survey Report for 1855.

1855. On the Characteristics of some Bottoms from the Cape Florida Gulf-Stream section. By Professor J. W. Bailey. Coast Survey Report for 1855.

1856. On the origin of Greensand and its Formation in the Oceans of the present Epoch. By Professor J. W. Bailey. Proc. Boston Soc. Nat. Hist., 1856.

1858. Report of Assistant L. F. Pourtalès on the Progress made in the Microscopical Examination of Specimens of Bottom from Deep-Sea Soundings. Coast Survey Report for 1858.

1858. On the Genera Orbulina and Globigerina. By L. F. Pourtalès, Assistant Coast Survey. Amer. Jour. of Sc. and Arts, 2d series, Vol. XXXVI. 1858.

1862. On the Origin, Growth, Substructure, and Chronology of the Florida Reef. By Captain E. B. Hunt, Corps of Engineers, U. S. A. Coast Survey Report for 1862.

* Plates representing the principal reef corals of Florida, prepared to accompany the full Report, but never published, have recently been completed, and will be soon issued by the Museum of Comparative Zoölogy.

1866. Report by Henry Mitchell, Assistant U. S. Coast Survey, upon Soundings across the Straits of Florida. Coast Survey Report for 1866.

1867. Report of Assistant H. Mitchell, Coast Survey, on Soundings made to develop the Character of the Straits of Florida between Key West and Havana. Coast Survey Report for 1867.

1867. Letters of Professor L. Agassiz on the Relations of Geological and Zoölogical Researches to General Interests in the Development of Coast Features. Coast Survey Report for 1867.

1867. Report on the Fauna of the Gulf Stream in the Straits of Florida. By L. F. Pourtalès. Coast Survey Report for 1867.

1867. Contributions to the Fauna of the Gulf Stream at great Depths. By L. F. de Pourtalès, Assistant U. S. Coast Survey. Bull. Mus. Comp. Zoöl., Vol. I. No. 6. Cambridge. 1867. pp. 18.

1868. Contributions to the Fauna of the Gulf Stream at great Depths (2d series). By L. F. de Pourtalès, Assistant U. S. Coast Survey. Bull. Mus. Comp. Zoöl., Vol. I. No. 7. Cambridge. 1868. pp. 22.

1868. Report of Assistant L. F. Pourtalès on Dredgings made in the Sea near the Florida Reef. Coast Survey Report for 1868.

1869. Report upon Deep-Sea Dredgings in the Gulf Stream during the Third Cruise of the U. S. Steamer Bibb, addressed to Professor B. Peirce, Superintendent U. S. Coast Survey. By L. Agassiz. Bull. Mus. Comp. Zoöl., Vol. I. No. 13. Cambridge. 1869. pp. 24. Also Coast Survey Report for 1869.

1869. The Gulf Stream. Characteristics of the Atlantic Sea-Bottom off the coast of the United States. By L. F. Pourtalès. Coast Survey Report for 1869.

1869. Preliminary Report on the Echini and Starfishes dredged in Deep Water between Cuba and the Florida Reef. By L. F. de Pourtalès, Assistant U. S. Coast Survey. Prepared by Alexander Agassiz. Bull. Mus. Comp. Zoöl., Vol. I. No. 9. Cambridge. 1869. pp. 56.

1869. Preliminary Report on the Ophiuridæ and Astrophytidæ dredged in Deep Water between Cuba and the Florida Reef. By L. F. de Pourtalès, Assistant U. S. Coast Survey. Prepared by Theodore Lyman. Bull. Mus. Comp. Zoöl., Vol. I. No. 10. Cambridge. 1869. pp. 46.

1869. List of the Crinoids obtained on the Coasts of Florida and Cuba by the U. S. Coast Survey Gulf Stream Expeditions in 1867, 1868, and 1869. By L. F. de Pourtalès, Assistant U. S. Coast Survey. Bull. Mus. Comp. Zoöl., Vol. I. No. 11. Cambridge. 1869. pp. 4.

1869. List of Holothuridæ from the Deep-Sea Dredgings of the United States Coast Survey. By L. F. de Pourtalès, Assistant U. S. Coast Survey. Bull. Mus. Comp. Zoöl., Vol. I. No. 12. Cambridge. 1869. pp. 3.

1870. Preliminary Report on the Crustacea dredged in the Gulf Stream in the Straits of Florida, by L. F. de Pourtalès, Assistant U. S. Coast Survey. Part I. Brachiura. Prepared by Dr. William Stimpson. Bull. Mus. Comp. Zoöl., Vol. II., No. 2. Cambridge. 1870. pp. 52.

1870. Der Boden des Golfstromes und der Atlanticschen Küste Nord Amerika's. Von L. F. v. Pourtalès, United States Coast Survey. Petermann's Geograph. Mittheilungen, 1870. Heft XI. pp. 5. 1 map.

1870. Grundzüge einer Spongien Fauna des Atlantischen Gebietes. Von Oscar Schmidt Leipzig. 1870. Fol. pp. 88. Pl. 6.

1871. Appendix to the Preliminary Report (Bull. No. 9, Vol. I.) on the Echini collected by L. F. de Pourtalès. By Alexander Agassiz. Bull. Mus. Comp. Zoöl., Vol. II. No. 5. Cambridge. 1871. pp. 3.

1871. Report on the Brachiopoda obtained by the U. S. Coast Survey Expedition in charge of L. F. de Pourtalès, with a revision of the Craniidæ and Discinidæ. By W. H. Dall, Assistant Coast Survey. Bull. Mus. Comp. Zoöl., Vol. III. No. 1. Cambridge. 1871. pp. 45. Pls. 2.

1871. Deep-Sea Corals. By L. F. de Pourtalès, Assistant U. S. Coast Survey. Illustrated Catalogue of the Mus. Comp. Zoöl., Vol. II. No. 4. (Memoirs, Vol. II. No. 4.) Cambridge. 1871. pp. 93. Pl. 8.

1871. Supplement to the Ophiuridæ and Astrophytidæ. By Theodore Lyman. Illustrated Catalogue of the Mus. Comp. Zoöl., Vol. II. No. 6. (Memoirs, Vol. II. No. 6.) Cambridge. 1871. pp. 14. Pl. 2.

1871. Contributions from the Laboratory of the Lawrence Scientific School. No. 13. On

some Rocks and other Dredgings from the Gulf Stream obtained by the Coast Survey. By S. P. Sharples. Amer. Jour. of Sc. and Arts. February, 1871. pp. 4.

1871. A letter concerning Deep-Sea Dredging, addressed to Professor Benjamin Peirce. By Louis Agassiz. Bull. Mus. Comp. Zoöl., Vol. III. No. 3. Cambridge. 1871. pp. 5.

1872. Echini of the Eastern Coast of the United States, together with a report on the Deep-Sea Echini collected in the Straits of Florida by L. F. de Pourtalès, Assistant U. S. Coast Survey, in the Years 1867–69. By Alexander Agassiz. (Being Part II. of the Revision of the Echini.) Illustrated Catalogue of the Mus. Comp. Zoöl., No. VII. (Memoirs of the Mus. Comp. Zoöl., Vol. III.) Cambridge. 1872–74. pp. 132. Pls. 42.

1872. Floridan Bryozoa, collected by Count L. F. de Pourtalès, Assistant Coast Survey, described by F. A. Smitt. Part I. Kongl. Svenska Vetenskaps Akad. Handlinger. Bandet 10, No. 11. Stockholm. 1872. pp. 20. Pls. 5.

Do. Part II. (*Ibid.*, Bandet 11, No. 4. Stockholm. 1873. pp. 83. Pl. 13.)

1873. Interim Report on the Hydroids collected by L. F. de Pourtalès during the Gulf Stream Exploration of the U. S. Coast Survey. By George J. Allman. Bull. Mus. Comp. Zoöl., Vol. III. No. 7. Cambridge. 1873. pp. 2.

1873. The Echini collected on the Hassler Expedition.* By Alexander Agassiz. Bull. Mus. Comp. Zoöl., Vol. III. No. 8. Cambridge. 1873. pp. 4.

1874. The Zoölogical Results of the Hassler Expedition. I. Echini, Crinoids, and Corals. By Alexander Agassiz and L. F. de Pourtalès. pp. 54. 15 woodcuts. Pls. 10. II. Ophiuridæ and Astrophytidæ, including those dredged by the late Dr. Stimpson. By Theodore Lyman. Illust. Cat. Mus. Comp. Zoöl., No. 8. (Memoirs, Vol. IV.) Cambridge. 1874. pp. 34. 4 woodcuts. Pls. 5.

1875. Corals at the Galapagos Islands. By L. F. de Pourtalès. Amer. Journ. of Sc. and Arts, 3d series, Vol. 10. 1875.

1875. Mission scientifique au Mexique et dans l'Amérique centrale. Recherches zoologiques 5e Partie. Études sur les Xiphosures et Crustacés podophthalmaires par M. Alphonse Milne Edwards. Paris. 1875. (Not completed, contains description of part of the Crustacea of the Gulf Stream Explorations and Hassler Expedition.)

1875. Révision des Stellérides par Edmond Perrier. Annales de Zoologie et de Physiologie experimentale. T. IV. Paris. 1875. (Same remark as preceding.)

1876. Die Schlangen und Eidechsen der Galapagos Inseln von Dr. F. Steindachner. Festschrift der K. K. Zool. Bot. Gesell. in Wien. 1876. pp. 29. Pls. 7. (Based in part on specimens collected in the Hassler Expedition.)

Dr. Steindachner has described fishes collected in the Hassler Expedition, in "Sitzungsber, der K. K. Akad. der Wissensch. in Wien," passim.

1876. E. v. d. Broeck, Étude sur les Foraminifères de la Barbade, recueillis par L. Agassiz Hassler Expedition, précédée de quelques considérations sur la classification et la nomenclature des Foraminifères. Ann. Soc. Belg. Micr. II.

1877. Report on the Hydroida collected during the exploration of the Gulf Stream by L. F. de Pourtalès, Assist. U. S. Coast Survey. By George J. Allman. Mem. of the Mus. Comp. Zoöl. Vol. V. No. 2. Cambridge. 1877. pp. 66. Pls. 34.

* On the voyage from Boston to San Francisco.

ADDENDUM TO APPENDIX No. 15.

TABLE SHOWING THE MODE OF REDUCING THE EXPERIMENTS.

Reduction of experiments at various pressures.

HEAVY END UP.

At 30 inches.

1st correction = Correction for expansion from 15° C. Coef. of exp. = 184×10^{-7}.
2d correction = *First* atmospheric correction adopting the *à priori* values, p. 272.
3d correction = *Second* atmospheric correction adopting the *à priori* values, p. 272.
4th correction = Correction for flexure of support, bells, and cylinder.

1877.	December 12.		December 14.	December 23.	
	s.	s.	s.	s.	s.
T_u corrected for rate..	1. 0065439	1. 0065349	1. 0065247	1. 0065517	1. 0065695
1st correction	+ 395	+ 326	+ 510	+ 455	+ 491
2d correction	— 151	— 149	— 267	— 320	— 330
3d correction..........	— 7	— 8	— 14	— 19	— 19
4th correction.........	— 209	— 209	— 209	— 209	— 209
T_u	1. 0065467	1. 0065309	1. 0065267	1. 0065424	1. 0065628

RECAPITULATION.

		s.
1877, December 12	T_u =	1. 0065389
14	=	5267
23	=	5526
Mean..................	T_u =	1. 0065394

At 29 inches.

1877.	December 12.	December 16.	
	s.	s.	s.
T_u corrected for rate..	1. 0065322	1. 0065448	1. 0065421
1st correction	+ 380	+ 426	+ 407
2d correction..........	+ 40	+ 3	+ 8
3d correction	+ 10	+ 7	+ 7
4th correction.........	— 209	— 209	— 209
T_u	1. 0065543	1. 0065675	1. 0065634

RECAPITULATION.

		s.
1877, December 12	T_u =	1. 0065543
16	=	5654
Mean	T_u =	1. 0065599

At 27 inches.

1877.	December 16.	
	s.	s.
T_u corrected for rate..	1. 0064775	1. 0064574
1st correction	+ 426	+ 426
2d correction..........	+ 429	+ 429
3d correction..........	+ 50	+ 50
4th correction.........	— 209	— 209
T_u	1. 0065471	1. 0065270
Mean.................. T_u = 1s. 0065370		

Reduction of experiments at various pressures—Continued.

HEAVY END UP—Continued.

At 22.5 *inches.*

			s.
1877, December 16.		T_u =	1.0063670
	1st correction....	= +	388
	2d correction....	= +	1478
	3d correction....	= +	161
	4th correction....	= −	209
		T_u =	1.0065488

At 15 *inches.*

			s.
1877, December 17.		T_u =	1.0061782
	1st correction....	= +	415
	2d correction....	= +	3099
	3d correction....	= +	362
	4th correction....	= −	209
		T_u =	1.0065449

At 7.5 *inches.*

1877.	December 4.	December 17.
	s.	s.
T_u corrected for rate	1.0059540	1.0059831
1st correction	+ 537	+ 407
2d correction	+ 4746	+ 4757
3d correction	+ 627	+ 629
4th correction	− 209	− 209
T_u	1.0065241	1.0065415
Mean T_u =	1s.0065328	

At 1 *inch.*

			s.
1877, December 19.	T_u corrected for rate	=	1.0057813
	1st correction.......	= +	435
	2d correction.......	= +	6170
	3d correction.......	= +	1031
	4th correction.......	= −	209
	T_u	=	1.0065240

Reduction of experiments at various pressures—Continued.

HEAVY END UP—Continued.

At .82 to .67 inch.

1877.	December 10.		December 19.	December 22.	December 23.
	s.	s.	s.	s.	s.
T_u corrected for rate	1. 0057778	1. 0057669	1. 0057752	1. 0057813	1. 0057741
1st correction	+ 465	+ 497	+ 429	+ 460	+ 486
2d correction	+ 6242	+ 6230	+ 6248	+ 6211	+ 6209
3d correction	+ 1071	+ 1065	+ 1077	+ 1054	+ 1053
4th correction	− 209	− 209	− 209	− 209	− 209
T_u	1. 0065347	1. 0065252	1. 0065297	1. 0065329	1. 0065280

RECAPITULATION OF RESULTS AT .82 TO .67 INCH.

		s.
1877, December 10	T_u =	1. 0065300
19	=	297
22	=	329
23	=	280
Mean	T_u =	1. 0065301

At .46 to .35 inch.

1877.	November 30.	December 8.		December 22.	December 23.
	s.	s.	s.	s.	s.
T_u corrected for rate	1. 0057784	1. 0057597	1. 0057579	1. 0057628	1. 0057611
1st correction	+ 383	+ 501	+ 497	+ 451	+ 487
2d correction	+ 6303	+ 6311	+ 6297	+ 6305	+ 6288
3d correction	+ 1119	+ 1126	+ 1113	+ 1120	+ 1106
4th correction	− 209	− 209	+ 209	− 209	− 209
T_u	1. 0065380	1. 0065326	1. 0065277	1. 0065295	1. 0065283

RECAPITULATION OF RESULTS AT .46 TO .35 INCH.

		s.
1877, November 30	T_u =	1. 0065380
December 8	=	301
22	=	295
23	=	283
Mean	T_u =	1. 0065315

HEAVY END DOWN.

At 30 inches.

1877.	September 25.	September 27.	October 5.	
	s.	s.	s.	s.
T_d corrected for rate	1. 0064173	1. 0064194	1. 0063979	1. 0063913
1st correction	− 470	− 516	− 321	− 311
2d correction	− 9	− 4	− 17	− 18
3d correction	− 3	− 5	− 4	− 4
4th correction	− 168	− 168	− 168	− 168
T_d	1. 0063523	1. 0063501	1. 0063469	1. 0063412

RECAPITULATION.

		s.
1877, September 25	T_d =	1. 0063523
27	=	501
October 5	=	441
Mean	T_d =	1. 0063488

Reduction of experiments at various pressures—Continued.

HEAVY END DOWN—Continued.

At 15 *inches.*

1877.	September 26.	October 5.	
	s.	*s.*	*s.*
T_d corrected for rate	1.0062457	1.0062378	1.0062306
1st correction	− 392	− 321	− 311
2d correction	+ 1380	+ 1396	+ 1396
3d correction	+ 157	+ 160	+ 160
4th correction	− 168	− 168	− 168
T_d	1.0063434	1.0063445	1.0063383

RECAPITULATION.

		s.
1877, September 26	T_d =	1.0063434
October 5	=	314
Mean	T_d =	1.0063374

At 5 *inches.*

			s.
1877, October 1.	T_d corrected for rate	=	1.0061379
	1st correction	= −	506
	2d correction	= +	2329
	3d correction	= +	325
	4th correction	= −	168
	T_d	=	1.0063359

At 1.5 *inches.*

			s.
1877, October 1.	T_d corrected for rate	=	1.0060999
	1st correction	= −	490
	2d correction	= +	2651
	3d correction	= +	427
	4th correction	= −	168
	T_d	=	1.0063419

At 0.5 *inch.*

			s.
1877, September 29.	T_d corrected for rate	=	1.0060879
	1st correction	= −	506
	2d correction	= +	2744
	3d correction	= +	479
	4th correction	= −	168
	T_d	=	1.0063428

At 0.25 *inch.*

			s.
1877, October 3.	T_d corrected for rate	=	1.0060746
	1st correction	= −	516
	2d correction	= +	2767
	3d correction	= +	501
	4th correction	= −	168
	T_d	=	1.0063330

Reduction of the regular set at Hoboken.

HEAVY END DOWN.

		s.
Mean T_d corrected for rate, temperature, and pressure	=	1.0063565
Correction for cylinder	= −	36
Correction for flexure	= −	89
		1.0063440
Correction for improved constants	−	2
T_d	=	1.0063438

HEAVY END UP.

		s.
Mean T_u corrected for rate, temperature, and pressure	=	1.0065487
Corrected for cylinder	= −	71
Corrected for flexure	= −	39
		1.0065377
Correction for improved constants	= −	3
T_u	=	1.0065374

Reduction of experiments at high temperatures.

HEAVY END DOWN.

The half set.

		s.
Mean T_d corrected for rate and pressure and reduced to 35° C.	=	1.0065357
Reduction to 15° C. Correction for expansion	= −	1850
Correction for atmospheric effect—*First* part	= +	181
Second part	= +	5
Correction for flexure, bells, and cylinder	= −	168
T_d	=	1.0063525
Correction for erroneous temperature	= −	65
		1.0063460

HEAVY END UP.

The half set.

		s.
Mean T_u corrected for rate and pressure, and reduced to 35° C.	=	1.0067097
Reduction to 15° C. Correction for expansion	= −	1850
Correction for atmospheric effect—*First* part	= +	414
Second part	= +	10
Correction for flexure, bells, and cylinder	= −	168
T_u	=	1.0065503
Correction for erroneous temperature	= −	66
		1.0065437

Reduction of experiments at high temperatures—Continued.

HEAVY END UP—Continued.

At 30 inches (not included in half set).

		s.
Mean T_u corrected for rate and pressure, and reduced to 35° C.	=	1.0066882
Correction for inequality of knives	= +	74
Reduction to 15° C. Correction for expansion	= −	1850
Correction for atmospheric effect—*First* part	= +	414
Second part	= +	10
Correction for flexure, bells, and cylinder	= −	168
T_u	=	1.0065362
Correction for erroneous temperature	= −	66
		1.0065296

At 2.25 inches.

			s.
1878, April 26.	T_u corrected for rate and brought to 35° C ...	=	1.0060497
	Correction for inequality of knives	= +	74
	Correction for expansion from 15° C	= −	1850
	Correction for atmosp. effect—*First* part ..	= +	5935
	Second part.	= +	919
	Correction for flexure, bells, and cylinder.	= −	168
	T_u	=	1.0065407
	Correction for erroneous temperature	= −	78
			1.0065329

At 1.25 inches.

			s.
1878, April 24.	T_u corrected for rate and brought to 35° C ...	=	1.0060088
	Correction for inequality of knives	= +	74
	Correction for expansion from 15° C	= −	1850
	Correction for atmosp. effect—*First* part ..	= +	6138
	Second part.	= +	1007
	Correction for flexure, bells, and cylinder .	= −	168
	T_u	=	1.0065289
	Correction for erroneous temperature	= −	79
			1.0065210

Calculation of [T^2 *Inv.*] *and* [T^2 *Rev.*].

	Regular set.	Half set at high temperatures.	At 30 inches up and 30 inches down.	At 15 inches up and 15 inches down.	At 7½ inches up and 5 inches down.	At 1 inch up and 1½ inches down.	At $\frac{4}{10}$ inch up and ½ inch down.
	s.	s.	s.	s.	s.	s.	s.
T_d corrected for rate, temperature, pressure, and wear of knife-edges	1.0063438	1.0063460	1.0063488	1.0063374	1.0063359	1.0063419	1.0063428
T_d^2	1.0127278	1.0127323	1.0127379	1.0127150	1.0127119	1.0127240	1.0127258
Reduction to Paris length	— 45	— 45	— 45	— 45	— 45	— 45	— 45
Corrected T_d^2	1.0127233	1.0127228	1.0127334	1.0127105	1.0127074	1.0127195	1.0127213
T_u corrected for rate, temperature, pressure, and wear of knife-edges	1.0065374	1.0065437	1.0065394	1.0065449	1.0065328	1.0065240	1.0065315
T_u^2	1.0131175	1.0131302	1.0131216	1.0131326	1.0131083	1.0130906	1.0131057
Correction for stretching	+ 10	+ 10	+ 10	+ 10	+ 10	+ 10	+ 10
Reduction to Paris length	+ 104	+ 104	+ 104	+ 104	+ 104	+ 104	+ 104
Corrected T_u^2	1.0131289	1.0131416	1.0131330	1.0131440	1.0131197	1.0131020	1.0131171
$\frac{1}{2}(T_d^2 + T_u^2)$	1.0129261	1.0129322	1.0129332	1.0129272	1.0129135	1.0129107	1.0129192
$\frac{1}{2}(T_d^2 - T_u^2)$	— 2028	— 2094	— 1998	— 2167	— 2061	— 1912	— 1979
$\frac{h_d - h_u}{h_d + h_u} \cdot \frac{1}{2}(T_d^2 - T_u^2)$	— 797	— 823	— 785	— 851	— 810	— 751	— 778
$\frac{h_d + h_u}{h_d - h_u} \cdot \frac{1}{2}(T_d^2 - T_u^2)$	— 5162	— 5330	— 5085	— 5515	— 5246	— 4866	— 5037
[T^2 Inv.]	1.0128464	1.0128499	1.0128547	1.0128421	1.0128325	1.0128356	1.0128414
[T^2 Rev.]	1.0124099	1.0123992	1.0124247	1.0123757	1.0123889	1.0124241	1.0124155

Calculation of [T^2 *Inv.*] *and* [T^2 *Rev.*] *at European stations.*

	Paris.	Berlin.	Kew.
	s.	s.	s.
T_d corrected for rate, temperature, pressure, and wear of knife-edges	1.0060510	1.0058980	1.0059296
T_d^2	1.0121386	1.0118308	1.0118944
Correction for flexure	— 1495	— 1495	— 1495
Reduction to Paris length	....	— 12	— 21
Corrected T_d^2	1.0119891	1.0116801	1.0117428
T_u corrected for rate, temperature, pressure, and wear of knife-edges	1.0061971	1.0060378	1.0060690
T_u^2	1.0124326	1.0121121	1.0121748
Correction for flexure	— 650	— 650	— 650
Correction for stretching	+ 10	+ 10	+ 10
Reduction to Paris length	....	+ 27	+ 47
Corrected T_u^2	1.0123686	1.0120508	1.0121155
$\frac{1}{2}(T_d^2 + T_u^2)$	1.0121788	1.0118654	1.0119292
$\frac{1}{2}(T_d^2 - T_u^2)$	— 1898	— 1854	— 1864
$\frac{h_d - h_u}{h_d + h_u} \cdot \frac{1}{2}(T_d^2 - T_u^2)$	— 746	— 729	— 732
$\frac{h_d + h_u}{h_d - h_u} \cdot \frac{1}{2}(T_d^2 - T_u^2)$	— 4832	— 4720	— 4744
[T^2 Inv.]	1.0121042	1.0117925	1.0118560
[T^2 Rev.]	1.0116956	1.0113934	1.0114548

LIST OF SKETCHES.

PROGRESS SKETCHES.

ILLUSTRATIONS.

LETTER

OF

THE SECRETARY OF THE NAVY,

COMMUNICATING,

In compliance with a Senate resolution of March 3, 1879, *the reports of survey of the Panama and Napipi interoceanic ship-canal routes made in* 1875.

NAVY DEPARTMENT,
Washington, March 7, 1879.

SIR: In compliance with a resolution of the Senate of the 3d instant, I have the honor to transmit the reports of survey of the Panama and Napipi interoceanic ship-canal routes made in 1875, with the accompanying maps.

Very respectfully,

R. W. THOMPSON,
Secretary of the Navy.

Hon. WILLIAM A. WHEELER,
Vice-President of the United States.

REPORT

OF

EXPLORATIONS AND SURVEYS

FOR THE

LOCATION OF A SHIP-CANAL

BETWEEN THE

ATLANTIC AND PACIFIC OCEANS

THROUGH THE

ISTHMUS OF PANAMA,

1875,

BY A UNITED STATES NAVAL EXPEDITION,

Commander EDWARD P. LULL, Commanding.

REPORT OF COMMANDER EDWARD P. LULL, U. S. N., COMMANDING EXPEDITION.

WASHINGTON, D. C., *November* 20, 1875.

SIR: I have the honor to present the following report of the operations of the United States surveying expedition lately employed in seeking a route for an interoceanic canal through the Isthmus of Panama.

The expedition was organized immediately upon the receipt of the following orders and instructions from the Department, viz:

NAVY DEPARTMENT,
Washington, D. C., December 29, 1874.

SIR: Upon the request of the Interoceanic Canal Commission for more specific information in relation to the Isthmus of Panama, in general in the vicinity of the line of railroad, you are detailed, and will proceed in the steamer of January 2, from New York for Aspinwall, with the party of officers ordered to report to you.

Your thorough experience in these matters relieves the Department from preparing minute and contingent instructions. You will, however, obtain specific information on the following points, viz:

1st. In relation to water-supply and the points whence it should be drawn for an interoceanic canal, if constructed upon the Isthmus of Panama.

2d. The difficulties that may exist from floods.

3d. Actual locations of the most practicable line or lines, with locations of locks, if the route, upon examination, should render this advisable.

4th. Observation as to whatever in the way of material or other conditions would look to the general question of construction, whether of advantage or disadvantage.

5th. To obtain in advance from the Panama Railroad Company whatever information as to levels, *known to be authentic*, the company may be disposed to give you, which may form a basis for your special careful instrumental examination.

6th. By the aid of a tug, and whatever other facilities may be necessary, to enter the Chepo River, making such examinations of it as may be thought advisable after inspection. It is suggested, if the near approach of massive solid ground on both sides of the Chepo should make it possible by dams to flood considerable areas and distances for slack-water navigation, that it might be found practicable in connection with a tunnel of considerable length to the Gulf of San Blas. If the prosecution of this examination should be found advisable, put it in such a shape as will not lead to doubts as to relative practicability.

If the short time given you to complete arrangements is insufficient, arrange to have shelter-tents, or whatever else is required, forwarded to you by the next steamer.

Paymaster F. H. Clark is assigned to your party, and a bill of credit is at Paymaster Cutter's office, drawn in your favor, for $3,000. It is supposed that an appropriation asked for will soon be passed for this work, when a further bill of credit will be sent to you, chargeable to that appropriation. If otherwise, your necessary expenses will be met in another way at an early day.

You are authorized to appoint a draughtsman at $150 per month, and an assistant at $50 per month, and, in general, to secure the services of such persons as may be necessary to the proper and speedy execution of this work, and you will keep the Department informed of its progress. You are also authorized to appoint a clerk.

Upon its completion you will return with your party; and, if the rainy season interrupts your work to such a degree as to render it advisable to leave, you will do so without special instructions from the Department, and proceed to this city with such of your party as may be found useful in bringing up the work, and order the remainder to their homes.

Very respectfully, your obedient servant,

GEO. M. ROBESON,
Secretary of the Navy.

Commander E. P. LULL, U. S. N.,
Torpedo Station, Newport, R. I.

I arrived in New York in obedience to the above order on the morning of the 30th, meeting by appointment Civil Engineer A. G. Menocal, U. S. N., who was attached to the expedition as chief engineer. We at once set about procuring the outfit for the expedition.

The experience of former years having made us thoroughly acquainted with our needs, we met with no delay; and, thanks to the kindness of the Department, the Bureaus of Navigation and of Provisions and Clothing, in approving by telegraph requisitions for money, instruments, and provisions; to the facilities afforded by the Vice-Admiral commandant of the New York station, and to the assistance rendered by Pay Director George F. Cutter, the purchasing pay-officer, we were enabled to sail January 5 (the mail-steamer having fortunately postponed her departure until that day), with our outfit complete in every particular.

The following officers were attached to the expedition, viz: Commander Edward P. Lull, United States Navy, commanding; Civil Engineer A. G. Menocal, United States Navy, chief engineer; Lieut. Eugene H. C. Leutzé, United States Navy; Lieut. H. G. O. Colby, United States Navy; Lieut. Edward W. Very, United States Navy; Lieut. Edward D. Taussig, United States Navy; Lieut. Jefferson F. Moser, United States Navy (joined January 25); Master John H. C. Coffin, United States Navy; Master Henry L. Greene, United States Navy; Assistant Surgeon John F. Bransford, United States Navy; Assistant Paymaster Frank H. Clarke, United States Navy; draughtsman, James B. Philp; commander's clerk, John E. Buck. Of these, Messrs. Menocal, Leutzé, and Moser were officers of large experience in this character of work, having served in several previous expeditions. Dr. Bransford and Mr. Buck had served in one of the Nicaragua expeditions. Five intelligent young men were engaged to serve as rodmen, polemen, and chainmen.

The expedition was provided with the following instruments, the greater part of which had been used in previous surveys, viz: Two transits, three spirit-levels, two gradienters, three sextants, one artificial horizon, two pocket aneroid barometers for measuring heights, one current-meter, three 100-feet chains, one 50-feet chain, three binocular field-glasses, three sets of drawing-instruments, together with the necessary field note-books, stationery, drawing materials, &c.

The outfit consisted of 36 shelter-tents, made of light duck water-proofed, 36 mosquito-bars, 18 knapsacks, 24 rubber blankets, 15 rubber pillows, 36 ship's hammocks, 36 canteens, 72 pairs of leggings, 100 pairs of shoes, 36 tin pots, pans, and spoons, 24 machetas, 6 axes, 6 hatchets, 6 camp-kettles, 6 frying-pans, 2 geologist's hammers, 4 lanterns, 2 dozen porcelain-lined iron plates, &c.

Of provisions, there were only provided "soup and bouilli," tomato soup, sugar, coffee, and candles, and a small quantity of condensed milk, as the locality in which we were to work was near enough to the cities of Aspinwall and Panama to enable us to procure all other required articles from them.

The expedition sailed (with the exception of Lieutenant Moser, ordered to proceed in the following steamer) January 5, 1875, in the Pacific Mail Steamship Acapulco, from New York, and arrived in Aspinwall on the 14th of the same month. Through the courtesy of Mr. William Thompson, the superintendent of the Panama Railroad, there was put at our service, without cost, a store-room, into which all the property of the expedition was placed until needed.

It was resolved to place two parties in the field, and these were organized at once.

Party No. 1 consisted of the following officers and others: Lieut. E. H. C. Leutzé, commanding; Lieut. E. W. Very, in charge of transit; Master J. H. C. Coffin, in charge of spirit-level; H. S. Fleming, rodman; Mancel Philp, chainman; Charles A. Smith, poleman.

Party No. 2 consisted of: Lieut. H. G. O. Colby, commanding; Lieut. E. D. Taussig, in charge of transit; Master H. L. Greene, in charge of spirit-level; Clerk J. E. Buck, to lead the line; J. H. Westerfield, chainman; Robert S. Burnett, rodman.

This arrangement continued until the arrival, on the 25th of the same month, of Mr. Moser, who was assigned to the charge of the level in Lieutenant Colby's party, and Mr. Greene was transferred to that of Lieutenant Leutzé, where he was placed at the head of the line. The paymaster and draughtsman were stationed at Aspinwall, which was made a depot of supplies. This arrangement left the commanding officer, the chief engineer, and Dr. Bransford free to move from party to party, as occasion required.

THE PROBLEM.

It having been concluded, from our previous knowledge of the best profile obtainable across the Isthmus of Panama, that a thorough cut from tide-water to tide-water, or, in other words, a canal without locks, was impracticable, at least in a commercial sense, and consequently that water for the canal must be drawn from some other source than the seas themselves, the question of water-supply became, as your instructions state, the first and most important point to be considered; for unless that could be satisfactorily solved, no other question need be considered at all. The requirements were an ample supply at the dryest season of the year, and an ample escape for the superabundant waters at other times, which latter phase of the subject was quite as important as the former. After fulfilling these conditions, the next part of the problem was to obtain the most favorable location for the line, combining the question of profile, distance, the avoidance of insurmountable obstructions, and the debouchment into harbors or localities where harbors could be built at cost within the limits of commercial practicability.

The character of the excavation and the supply of materials for construction were important though subordinate questions.

As is well known, a railroad exists between the ports of Aspinwall, or Colon, on the Caribbean, and Panama, on the Pacific. This road was built after a careful and exhaustive survey made by several eminent American engineers, and doubtless its profile is the most favorable for a railroad that could be found. The surveys upon which the road was constructed had developed a knowledge of the topography of that portion of the Isthmus to a degree that saved us a vast deal of work which had attended most other expeditions for the same purpose, viz, the elimination of lines more or less promising, and which have to be examined at least far enough to demonstrate their impracticability. The rivers, including many of the small mountain streams, were located both upon the published maps and upon the plans in possession of the railroad company with a tolerable degree of accuracy, and the coast-line on either side was well located upon marine charts. Mr. Thompson, the superintendent of the road, and his successor, Mr. White (who, by the way, had been our fellow-passenger in the Acapulco), kindly placed at our disposal all of the maps, plans, and profiles in their possession.

By a glance at the map it will be seen that the general trend of the Isthmus of Panama is east and west, the port of Panama lying almost southeast of Aspinwall. The river Chagres takes its rise somewhere in the vicinity of San Blas (its exact source is not known), flows in a generally west-southwest direction until it reaches the village of Matachin, near which it turns to the northwest and flows in a tortuous course to the Caribbean, its mouth being some seven miles to the westward of Aspinwall. This river is the only source from which an adequate supply of water can be obtained for a canal, and indeed it was much doubted by most persons familiar with it whether in the dry season even that source could be depended upon. To this river, then, or no where were we to look for the solution of the first point of our problem.

The question of the termini had next to be looked to. The Bay of Aspinwall, or Navy Bay as it is called upon the old charts, although exposed to northers, which are fortunately rare upon the coast, is a harbor reasonably secure from the prevailing northeast trade-winds. It is very commodious, and could easily be rendered entirely safe in all weathers.

There is no harbor within accessible distance to the westward of Aspinwall or any chance of constructing one without enormous cost. The mouth of the Chagres can only be entered by coasters of the smallest class. To the eastward, and distant some eighteen miles from Aspinwall, there is the beautiful harbor of Porto Bello. Our choice for an Atlantic terminus lay between these two harbors, and the reasons which decided us upon which one to choose will be given

further on. On the Pacific, we had the great bay of Panama into which to debouch at any point where it should prove most advantageous.

In 1843 a plan was published by Mons. Garrella, a French engineer, for a canal across the Isthmus, and is thus described by Rear-Admiral Davis in his report to Congress on the subject of interoceanic canals, 1866:*

This route was selected only after a careful inspection of the intervening space and after making the requisite levelings. It will be seen by this map that he follows the valleys of Bernardino and Caimito on the southern descent, and those of Inebrado and Chagres on the northern. The mountainous region approaches very near the Pacific, and its highest elevation is 459 feet above the level of the sea. He tunnels the mountain at about 99 meters (324 feet 9 inches) below its highest point; and he establishes his summit-level for a distance of 25,361 feet at an elevation of 135 feet above high-water from the Pacific Ocean. From this summit-level he descends to the Pacific Ocean by means of seventeen locks, some of which are necessarily very much crowded. On the other side he descends to the Atlantic by eighteen locks, which, owing to the more gradual descent on the north, are more conveniently spaced.

It is remarked by the commissioners of the "ponts et chaussées," appointed to report on Mr. Garrella's project, that his mode of proceeding is reasonable, and entirely in conformity with the rules of art.

A glance at the plan and profile shows that the near approach of the chain of the Andes to the Pacific Ocean obliges him to pursue the course he has adopted. Of the whole length of the summit-level, 17,550 feet are subterranean; and, as the commission observes, this is not only inconvenient to vessels, but it involves great expense, since the tunnel must be sufficiently high to allow vessels to pass through with their lower masts, at least, standing.

The means of feeding the canal are not satisfactorily stated. The river Chagres was gauged, it is true, at Cruces and at Gorgona, but the river is to be tapped above these points. Provision is also made for an auxiliary reservoir; still, the commission is not satisfied on this question.

The harbors which form the termini of the canal are, on the Atlantic side, Navy Bay, and on the Pacific side the bay of Vaca del Monte.

Garrella proposed to use the bed of the Chagres for a portion of the distance; and, in order to reduce his profile, proposed to occupy the valleys of small streams, without making provision for the waters of these streams except by receiving them into the canal. His plan was based upon very limited knowledge of the topography of the country; and, in the light of our present information, has not a feature worth considering.

Much more recently, during or after the construction of the railroad, plans and estimates were made by Colonel Totten, the distinguished chief engineer of the road, for a canal to be located in the vicinity of the road itself, and drawing its waters from the Chagres by means of a feeder. Colonel Totten's estimates were furnished me by Commodore Ammen, Chief of the Bureau of Navigation, and also by Prof. J. E. Nourse, U. S. N. No maps or profiles, however, could be obtained showing the exact location. A few pencil lines upon one of the maps lent us by the superintendent of the road were supposed by him to indicate Colonel Totten's line; but, as our own subsequent location differed from it very materially, I was led to doubt whether this was the case; nor have I been able to ascertain whether Colonel Totten actually made a survey for the canal route, or whether this estimate was made upon his knowledge of the topography obtained during the survey of the road. In the absence of this information, we were obliged to locate our line altogether for ourselves, as much so as if no plan had ever been proposed by him.

PRELIMINARY RECONNAISSANCE.

January 16, Mr. Menocal and myself, taking with us maps and profiles, passed over the line of the railroad on a general reconnaissance, with the view of acquiring such information as we could before laying out the work of the expedition.

By examining numerous high-water marks, we found that the river Chagres, at that time at its low stage, was subject to freshets which elevated its surface not less, in extreme cases, than 35 feet. All idea, therefore, of making a combined use of its bed and of independent canal for ship navigation, as proposed by Mr. Garrella, had to be abandoned at once, particularly in view of the great suddenness of these freshets. The high-water marks had been carefully preserved by several persons, and their elevation was measured with the spirit-level.

We had already decided that the Atlantic terminus must be to the eastward of the mouth of the Chagres; this involved the necessity of the canal's crossing the river, and one of the main

*Report on Interoceanic Canals and Railroads between the Atlantic and Pacific Oceans, by Rear-Admiral Charles H. Davis, Superintendent U. S. Naval Observatory, 1866.

objects of our reconnaissance was to determine approximately where the crossing should be. As the enormous variation in the amount of the river-flow precluded the possibility of receiving its waters directly into the canal, an aqueduct—or probably a better term would be viaduct—had to be provided for, through culverts under which, the waters of the river should pass. The culverts must be made of sufficient dimensions to pass the water at its highest stage. A brief computation showed what must be the difference of level between the surface of the water in the proposed viaduct and the surface of the river at its then stage, thus:

	Feet.
For rise of river*	35
Spring of arch of culvert	15
Thickness of wall over crown of arch	6
Depth of water in viaduct	26
Total	82

The summit-elevation of the canal could, therefore, not be less than 82 feet above that of the river at the point of crossing, computing from the lowest stage of the water in the river. All references to the level of the river surface will hereafter refer to that stage, unless otherwise specified.

By referring to the profile of the railroad, we found that the river at the great bend near Matachin, and just above the confluence with the river Obispo, was approximately 42 feet above mean tide of either sea; this added to the 82 feet would make, should that point be chosen for the crossing, 124 feet as the summit-level of the canal. An elevation of 124 feet would involve at least twelve lift-locks on either side, or twenty-four in all. This we regarded as the greatest number admissible, particularly in comparing the line with that through Nicaragua, where only ten of a side were required. This decided us that we could not go any higher up the river; or, in other words, that the line, at least at the point of crossing, could not be carried any farther to the eastward. A direct line drawn from Porto Bello to Panama would pass considerably to the eastward of this point, and a line drawn from this point to Porto Bello would be several miles longer than one drawn to Navy Bay or Aspinwall. In addition to this argument in favor of the selection of Aspinwall, was the unmistakable evidence that a much higher profile would be found in the direction of Porto Bello, which existed in the fact that the Chagres received numerous not inconsiderable tributaries from that direction, known to take their rise far to the eastward.

This locality presented some other features favorable for a point of crossing, mainly in the conformation of the ground on either side. The profile of the cross-section showed good abutments for the ends of the viaduct and at the same time ample room in the valley of the stream for the construction of culverts for the escape of the river-flow. The exact point was, of course, not chosen until several cross-sections had been taken, but the immediate vicinity of the bend was determined upon at the first reconnaissance as the place in which to seek for it. The bend is on the Atlantic slope of the Cordillera, and, on the line of the railroad, is but six miles from the dividing summit.

Passing the divide, we found the descent of the Pacific slope quite rapid, and by examining the profile of the railroad, it appeared that with a summit-level of 124 feet we should have a deep cut of but little more than five miles in length, even if we could not improve on that profile, which we hoped to do. A lower summit-level would, of course, increase the length of the deep cut, which consideration added to our determination not to seek a lower point of the river for crossing.

Having completed our preliminary examination, we proceeded to Panama to make arrangements for procuring laborers to act as *macheteros*, or choppers, and some supplies. Calling upon an old personal friend of my own, Mr. Henry Lewis, we were by him introduced to Messrs. Dellatorre & Co., resident merchants, whose kind offices he solicited for us. These gentlemen, both in a business way and through personal attentions of two members of the house (Mr. Dellatorre and

*The extreme height attained by the water in time of freshets is due to a considerable extent to the backing up of the water from below, and could be very largely prevented by clearing off the timber in the short bends of the river below, as I took occasion to suggest to the railroad authorities who are occasional sufferers from the encroachments of the floods. In the above computations we have set down the highest known level of the water as that which it is necessary to provide for, though for the reasons here stated I do not think, with proper precautions, it would ever be reached.

Don Geraldo Lewis), facilitated us in every manner in their power during the whole time of our stay upon the Isthmus, and put us under many lasting obligations.

I also took occasion to call upon Dr. Long, the United States consul, to ask him to notify the President of Panama of the arrival of the expedition, and to ask the President to appoint a day when I could call upon him and pay my respects.

On the following Monday, January 18, I called upon the President, with the consul, and explained briefly my instructions. The President expressed himself very much pleased with the object of the expedition, and the interest of the United States in prosecuting the work, and offered us every facility in our labors. This offer he afterward made good by directing the alcaldes of the various districts through which we were to pass to aid us in any manner in their power. We had no occasion, however, to avail ourselves of their assistance.

In the mean time Lieutenants Leutzé and Colby were completing the organizations of their parties, issuing instruments, outfits, &c., and the officers in charge of the transits and levels were employed in adjusting their instruments, and in running a few trial-lines to drill their assistants, &c. Four days were thus spent, making each person entirely familiar with his work.

BEGINNING OF OPERATIONS.

January 20, having procured through Messrs Dellatorre & Co. the necessary number of macheteros, I proceeded with them to Matachin, where I was met, by previous arrangement, by Messrs. Leutzé and Colby, with their parties, camp-equipments, &c. A camp was formed in common by the two parties on the bank of the Chagres, about a mile above Matachin, near where we proposed to begin work. The encampment was called "Camp Ammen," in honor of the Chief of the Bureau of Navigation, for the great interest taken by him in the interoceanic canal question and the assistance he had rendered to the various expeditions employed in attempting its solution.

To each party were now attached, in addition to the officers and assistants already mentioned, one cook, one servant, and nine macheteros, this having been found by our experience in former expeditions to be the minimum number consistent with efficiency. A whole day was devoted to the construction of the first camp, in order to thoroughly instruct those persons who had not served before; good shelter at night and a comfortable place in which to sleep being very important factors in the preservation of health, and, consequently, of efficiency. It was wonderful how expert each officer and man afterward, and very soon, became in erecting tents, &c. A ridge-pole and two side-poles, supported on forked stakes, properly braced, and the whole tied together with the tough flexible vines which abound throughout the region, formed the frame-work over which a shelter-tent was stretched, usually large enough to accommodate four persons. For a sleeping arrangement, each person was supplied with a ship's hammock, to each side of which was attached a stout pole; between the ends of these side-poles short pieces, called spreaders, were secured to hold the hammock out flat or nearly so; four forked stakes of convenient height driven into the ground supported the whole. A mosquito-bar, an India-rubber blanket and pillow, and a pair of woolen blankets completed the affair, and an exceedingly comfortable bed it made. As was the case in Nicaragua, we seldom found a night while in the interior when it was warm enough to sleep without blankets. The natives—employed as macheteros—generally preferred rolling themselves up in their blankets and sleeping upon the ground to taking any trouble in preparing a bed.

After a thorough local reconnaissance, conducted by Mr. Menocal, cross-sections were taken, and the exact site of the viaduct selected. The stream was gauged at the same time, using a delicate current-meter for testing the velocities at different points in the cross-section. The daily discharge was found to be 87,350,400 cubic feet.

It was then decided that Lieutenant Leutzé, with party No. 1, should locate the feeder. For this purpose he was instructed to run the traverse and levels up the river Chagres, following its bed until he should find an elevation, at the surface of the water above the water-surface at the site of the viaduct, of 87 feet plus 1 foot for each mile of distance from the starting-point, or until he should find a good location for a dam, by which the waters could be raised to that elevation. If this last could be done, as it was hoped and afterward shown that it could be, it would of course materially diminish the length of the feeder. It might here be explained that the valley of the

river is inclosed on either side by numerous ranges of hills, sometimes approaching the river-banks and again receding from it.

At the site of the proposed viaduct the valley is so narrow that the length of the viaduct would require to be but 1,600 feet. An equally favorable location for the dam was the object of Mr. Leutzé's search. On succeeding in this, he was to return on a grade-line, if possible, until he should intersect the line of the canal itself, striving to make the shortest distance consistent with the retention of the grade, which was to begin at the level to which it was proposed to raise the water-surface of the river, and to descend gradually until the proposed level of the canal was reached at the intersection.

To Lieutenant Colby and his party was assigned the work of locating the canal between the end of the viaduct and Panama Bay.

As it could not be told what difficulties would be met with by either party, it could not be predicted which would finish first the work now in hand; the division of what remained was, therefore, left for future consideration.

In planning the work, as in all other matters relating to the survey, Mr. Menocal was freely consulted, and his advice as freely taken, always to the securing of the best results in the obtaining of information with the most economical expenditure of time and labor.

As a test of the accuracy of the levelers, upon whose work so much depended, before starting upon the main lines each was required to run a line from the water's edge, at the site of the viaduct, establishing an initial bench-mark, to the railroad-track near Matachin, a distance of about a mile, and to return to the starting-point. Their results differed by less than two-tenths of an inch from each other and from coincidence with the level of the bench.

One or two mishaps occurred at the outset, such as the breaking of a tripod and the bending of a vernier-arm, each of which caused a little delay, but by the end of three or four days the parties were fairly under way and making good progress.

Lieutenant Leutzé's party followed the bed of the river generally, but cutting off the bends whenever possible, in order to shorten the distance. This involved crossing the stream very often. The current in many places was quite strong, with occasional rapids. The water varied in depth from a few inches to 15 and 20 feet, making it very laborious for the party. Much greater progress could be made in the river, however, than by cutting a trail on shore, and for that reason it was followed. After one or two days' work the party began to accomplish from 10,000 to 12,000 feet per day.

Lieutenant Colby's party started on a general compass-course of south 29° east toward a point which had been chosen for crossing the divide, with directions to make the best profile possible; in other words, to follow a line which could give the least depth of excavation except when to do so would so greatly increase the distance as to counterbalance or more than counterbalance the gain, to adjust which points often requires the greatest judgment and care.

After passing the ridge of high ground immediately adjacent to the river, and upon which the viaduct was to abut, the line fell into a valley where the ground was found very much below the level proposed for the viaduct. We had determined, for reasons already given, to make the latter the summit-level of the canal, and consequently to carry it through the divide until it intersected the surface on the opposite, or Pacific slope. It therefore seemed as if a considerable detour to the left would have to be made to keep on the grade-line, or else that the low land would have to be crossed by means of a second viaduct. After some further examination in various directions, it was found that they were in a valley opening to the right and falling into that of the Obispo, but toward the left ascending until it was finally lost at the junction of the two ridges which formed it. Continuing the line 1,970 feet, the grade-level was again reached. It should here be explained that the line was running through a dense forest, with the usual interlacing of vines, undergrowth, &c., a trail having to be cleared with the machetas for every rod of advance, so that it was seldom that the eye could penetrate a dozen yards in any direction.

It was only, therefore, by the laborious process of running trial-lines in various directions, cutting one's way through the jungle, that any idea of the immediate conformation of the ground could be obtained. These reconnaissances were made with the pocket aneroid barometers and with pocket-compasses. Each officer was supplied with a heavy sheath-knife, without the vigorous use

of which it was frequently impossible to move at all, so intricate is the net-work of tough flexible vines; a tree of considerable size, when cut down, will often be kept from falling by being attached to others by these vines, to the no small annoyance of the chopper.

After obtaining a knowledge of the formation of the valley above spoken of, Mr. Menocal proposed, as a substitute for the viaduct across it, to inclose it, with a dike on one side, making a basin of 22 acres in extent [see plan, Plate IV]; later, lines of levels were run for the location of the dike, which will be found estimated for. By this ingenious device what seemed at first an obstacle which it would be very expensive to overcome would be converted at moderate cost into a very desirable inland harbor.

This was but one of the numerous instances, both here and in the Nicaragua survey, where the judgment, the engineering skill, and the untiring energy of Mr. Menocal found remedies for our greatest apparent difficulties.

As has been said, the party was following in general a compass-course. Frequent reconnaissances had to be made to insure preserving the best profile, and deflections were made from the general course whenever it seemed advantageous. Several offsets a day were made to the right and to the left, for greater or less distances, to give as much as possible of the contours of the ground; the former were generally extended to the railroad-track. The reconnaissances were generally made by the chief of the party, accompanied by the chief engineer or the commanding officer, when present. With every precaution, it was occasionally found that the line was running into ground so unfavorable that it was necessary to go back for a distance and make a fresh start in a new direction.

By January 29, each party had extended its line so far that it was necessary to move camp. Striking tents, Mr. Leutzé, by means of canoes, proceeded some eight miles up the river, and established his party at "Camp Marguerita." The canoes, being deeply laden, were forced up with considerable difficulty against the strong current in the various rapids. Mr. Leutzé had acquired great skill in handling boats under similar circumstances during the Nicaragua expeditions, and succeeded in rapidly overcoming these difficulties, as he usually did in cases requiring the exercise of will, good judgment, and muscular force. Camp Marguerita was located some distance in advance of the head of the line, this being our invariable custom in moving camp, so that each of the next two or three days' work should bring the party at night nearer and nearer to their temporary home; then, passing it, a few days' further advance would make another move necessary.

Through the courtesy of Superintedent White, there was placed at the disposal of Mr. Colby and party, at Empire station, on the railroad, an unoccupied dwelling belonging to the railroad company. One of these exists at each four miles of road, having been formerly occupied by track-masters, now discontinued. Empire beiṅg at a convenient distance from the end of Mr. Colby's line, and the station-house having ample room to lodge his whole party, he was saved the time and trouble of erecting his tents. The moving was accomplished by means of canoes to Matachin, and thence by rail to Empire.

On the 4th of February, both parties progressing favorably, Mr. Menocal and myself went to Panama to make such examination as was necessary to determine at what point the line could advantageously debouch into the Bay of Panama. There is a good chart of the bay upon surveys made by English officers, and with that, and by making such soundings as we found necessary, we finally concluded that the most suitable point for debouchment would be about one-quarter of a mile to the eastward of the railroad company's wharf, a mile and a half approximately east of the city of Panama. The chief advantages of this point are, the easy approach from the point of crossing the divide; the proximity of deep water to the shore; the remoteness of any river-mouth to discharge detritus, and thus form obstructions; and the existence of a straight channel out to deep water, and not obstructed by reefs. We were indebted for some valuable information to Capt. John M. Dow, of the Pacific Mail Steamship Company, an accomplished navigator, and naturalist as well, and who, in the pursuit of both these callings for many years in the vicinity, has gained a most thorough knowledge of the hydrography of the Bay of Panama.

February 4, Lieutenant Leutzé's traverse had advanced so far up the river that he was again

obliged to move camp some seven miles. Each move was found to be more troublesome than the last, the current of the stream becoming stronger and the rapids more frequent.

About three miles above the site of the first camp is the village of Cruces, now containing some three or four hundred inhabitants. It is very old, having been built by the early Spanish occupants of the land. Notwithstanding its proximity to Matachin, the nearest railroad station, it has to that point no sign of a road, all communication being by water. Above Cruces, at least as far as our line extended, there are only here and there a few huts, and scarcely a vestige of cultivated ground. Very little could be purchased in the way of provisions, except milk, eggs, and occasion ally a chicken, and these not always. Nearly everything in the shape of supplies had to be forwarded from Panama or Aspinwall.

By February 9, Lieutenant Leutzé's line had reached a point on the river which he regarded as suitable for the erection of a dam; and Lieutenant Colby's party was in close proximity to the divide. Mr. Menocal proceeded to join Mr. Leutzé, to aid in the selection of the exact location of the dam and to procure such local information as was needed. On the same day, Lieutenant Very, in attempting to pass one of the rapids, was swept away by the powerful current, losing his transit-book, which involved the necessity of going back and retaking the lost angles. Fortunately, all the station-marks had been preserved.

Thorough local reconnaissances were made during the next two or three days by Messrs. Leutzé and Menocal. Cross-sections of the river and its immediate valley, and gauges of the stream, were taken. A capital site was chosen for the dam, a solid rock foundation and precipitous rocky banks for abutments on either side [see plan, Plate III]. The next object to be sought was a good starting-point for the feeder, which the immediate vicinity of the dam did not offer. The general character of the valley showed that the best location could be obtained on the left, *i. e.*, the southern bank. Nearly the whole of the 11th was spent in seeking a break in the wall of the rock forming the bank, but without success. On the 12th, at a distance of 4,800 feet above the site of the dam, an eligible spot was found. The traverse in ascending had taken so sharp a curve around to the southward and westward (Lieutenant Very having extended the survey up to that point), that the initial point of the feeder was really nearer to the main line of the canal than the site of the dam.

Lieutenant Leutzé and party now began their return on the grade-line. So devious were the contours of the surface, that a great deal of care and good judgment had to be exercised, reconnoitering constantly ahead, the problem made much the more troublesome, as has been explained, referring to Lieutenant Colby's line, from the fact that so little could be seen at a time. Generally at the end of each day's work an offset was cut to the river-bank, checking the work, and saving long distances in returning to camp and in gaining the line the following morning. It was a never-ending source of astonishment to the natives that the officers could start from a point in the dense forest and lead them so directly to the river-bank, and even directly to the camps when the distance was not too great.

In the mean time Lieutenant Colby with his party, accompanied by myself, was carrying his ine across the divide. The railroad in passing the summit makes a sharp curve around a hill, or between two hills, by which location a comparatively low pass was obtained; the curve was, however, of two small radius for a ship-canal. To avoid this, our line was carried across a somewhat higher ridge, though still through a considerable depression. To compensate for the increased height was a considerably decreased distance.

On the evening of the 9th, young Mr. Westerfield, the chainman, was taken down with quite a sharp attack of fever, having overtasked his strength. On the following day Dr. Bransford joined the party, having left Mr. Leutzé's camp the day before. His arrival was very opportune, for a few hours afterward an old negro employed as cook was seized with a congestive chill, of which he died within twenty-four hours, notwithstanding the utmost exertion on the part of the doctor. The poor old fellow, who had been upon the Isthmus for many years, and had by his manner of living completely exhausted his vital forces, did not rally in the least from the moment he was attacked; the strongest mustard-plasters placed on his wrists and kept there until he was dead failed to produce the least inflammation. Dr. Bransford had shown himself, during the

Nicaragua expedition, to be a master in the management of malarious attacks, and although we had two or three quite obstinate cases during our present expedition, this was the only one which failed to yield to his treatment. Young Westerfield was thoroughly well in a few days.

The divide was actually crossed on the 12th and the descent to the Pacific begun. A new compass-course was taken and followed, as before, as nearly as the conformation would admit of its being done. A good deal of trouble was experienced, in both parties, with the natives employed as macheteros, many of whom proved very worthless, feigning sickness, &c.; but by a judicious sifting process each party soon secured a good set of men, who continued to serve till the end of the survey.

February 16, Mr. Menocal came to Lieutenant Colby's party, and I proceeded to that of Lieutenant Leutzé, in order that each might see the important portions of the work that the two parties had just completed. Lieutenant Leutzé having made some little progress, on his return had shifted his encampment down the river and established "Camp Sunnyside."

As I arrived in camp, one of the men, in attempting to open a box, cut his arm very badly with a hatchet. The doctor being with the other party at the Empire station, Mr. Leutzé and myself did all in our power to check the profuse bleeding of the wound; but finding our success was only temporary, we were finally obliged to put the man into a canoe, in charge of Mr. Greene, who carried him down the river to Matachin, and thence by a hand-car to Empire. This determined me to make application for a second medical officer, in order that one might be present with each party, which I did by the next mail. The department sent to us Dr. Chiola, who arrived by return steamer.

Both parties were now making favorable progress; Mr. Leutzé unfortunately suffering from occasional attacks of fever, but refusing to give himself sufficient rest to recover from it. He had contracted the fever by overwork and exposure in the Nicaragua expedition, and really ought not to have joined a new survey, but that his zeal overmastered his prudence.

On the 17th, Mr. Colby was taken down with the fever, having also considerably overtasked his strength; the labor for the chiefs of the parties being necessarily very severe, and neither sparing himself in the least. A couple of days under Dr. Bransford's care brought Mr. Colby around, though he was not actually fit for duty for several days, and commenced work much sooner than he ought, but fortunately no harm resulted from it.

On the 18th the doctor, with the cooks, shifted camp to Rio Grande station, eight miles from Empire, where another of the track-master's cottages was put at the disposal of the party.

Lieutenant Taussig continuing the survey with the remainder of the party, no time was lost in the operation of moving. This party was operating in the valley of the Rio Grande, a dirty stream emptying into the Bay of Panama some two miles west of the city, and was making excellent progress toward the debouchment, the line crossing the stream frequently and running through swampy ground.

February 19, Lieutenant Taussig was taken with the fever, suffering one of the severest and most obstinate attacks that was experienced by any of the party. Mr. Menocal, being present, took charge of the transit and Lieutenant Moser of the line, so that the work was kept going.

February 24, the line was extended to the beach, at the point already chosen for the entrance into Panama Bay.

On the following day the camp was shifted to Obispo station, near Matachin, preparatory to making the detailed local examination for the artificial basin already spoken of. A couple of days were then given to officers and men for a much-needed rest.

On consultation with Mr. Menocal, it was now determined to reserve for Lieutenant Leutzé's party the section of the Atlantic division between the viaduct and Barbacoas, about twenty-one miles from Aspinwall, and to give to Mr. Colby's party from Barbacoas to Aspinwall.

By March 1, Mr. Colby's party had completed the detailed survey of the site of the basin, and had shifted camp to Frijoles, near the initial point of their new line. On the following day they established bench and station marks and began their new line.

In Mr. Leutzé's party the work of locating the feeder was being prosecuted with varying success. On the 23d of February, the valley of the Chilibri, a tributary of the Chagres, was reached. Here the level suddenly dropped to 22 feet below the grade-line. The valley was found to be some

3,000 feet wide. Two or three days were spent in trying to find a point, by ascending the stream, where the valley was enough narrower to compensate for the increased distance in reaching the point, but without success. Camp was shifted on the 24th to a position just below the mouth of the Chilibri, and called Camp Hunter.

In making the reconnaissances a clearing was found on the top of a hill overlooking the valley for miles up. Lieutenant Very climbed to the roof of a hut in the center of the clearing, from which he was able to get an excellent idea of the general topography. This was one of the few spots found during the whole survey offering any such advantage, trial-lines being as a general rule our only guides in cases of doubt. The low level of the valley was a serious obstacle, as the water would have to be carried across it either by an aqueduct or else by inverted siphons. It seeming to be inevitable, Mr. Leutzé had no alternative but to cross it at the narrowest place, without deflecting his line in any great degree, and to continue.

March 26, Mr. Coffin was sent to Mr. Colby's party for treatment for an abscess, Mr. Greene taking charge of the level.

On the 1st of March, joining Mr. Leutzé myself (a slight touch of fever having prevented my doing so before), we turned back to the Chilibri again, in order to exhaust the subject thoroughly before giving up the attempt to avoid the low ground, or at least to diminish the length of the crossing. Three days were spent in the effort, which was finally abandoned as impossible.

Mr. Leutzé now resumed the grade, following it as nearly as possible. On the 10th he shifted his party to Camp Ammen, which he re-established. On the 11th, Acting Assistant Surgeon T. Chiola, U. S. N., having arrived on the 9th and reported for duty, was assigned to Mr. Leutzé's party. Mr. Leutzé, being sadly in need of medical treatment, went the same day to Mr. Colby's camp to place himself in Dr. Bransford's hands, remaining for two or three days.

March 15, Mr. Leutzé brought the line of the feeder to an intersection with the line of the canal, debouching into the proposed artificial basin. Gauging the flow of the Chagres, he found the discharge to be 647 cubic feet per second—a considerable diminution since January 23, owing to the advance of the dry season.

On the following day the survey of the main line from the viaduct to the initial point of Mr. Colby's line was begun. The distance to be made was, in a straight line, but about eight miles, but was through rough and broken country, requiring exceedingly careful examination.

Lieutenant Colby's party were in the mean time making very good progress seeking the shortest distance consistent with a good profile; the usual number of reconnaissances, offsets, trial-lines, &c., being made to secure that end. On the 10th of March camp was shifted to the residence at Bohio station, which, except for the lack of good water, was one of the most comfortable locations thus far occupied.

RECONNAISSANCE OF THE BAYANO RIVER.

Mr. Menocal and myself, with Dr. Bransford and Paymaster Clark, now prepared to make the reconnaissance of the Bayano or Chepo River, required by your instructions. For this purpose, through the assistance of Mr. Theodore J. DeSabla, a merchant of Panama, and formerly United States vice-consul for that port, a small schooner was procured, the only means of transportation available. The schooner was the property of Dr. Kratochvil, a gentleman who had spent a fortune some years before in the establishment of a sugar-estate about twenty miles up the Bayano, and which, owing to the lack of laborers, he had been obliged to stop operating. His little vessel was now running between his place and Panama with dye and furniture woods, and also with wood for fuel.

Embarking the evening of the 15th of March, we reached the mouth of the Bayano on the following morning. Getting into an anchorage just at the last of the flood, we were obliged to come to and wait for the next flood before proceeding up the river. We took occasion to make such soundings as we needed inside the bar. There is a village of some twenty cane huts at the mouth of the river, called Boca del Bayano. At the turn of the tide we got under way and proceeded up the river some six miles, sounding as we went. We then dropped anchor till daylight; got under way again and carried our soundings ten miles farther up, when the tide again turned ebb, and the schooner was obliged to come to. We now took a wretched little canoe, and in her continued on three miles farther, to the estate of Dr. Kratochvil.

We were very hospitably received by the doctor, who gave us pleasant quarters and regaled us with all that his place afforded—abundance of fruit and vegetables, and, what was quite a new experience for each of us, with the flesh of the tapir, which we found very delicate and palatable.

It was a sad sight to see so magnificent a place, with fine buildings, abundant machinery, and other facilities, lying idle and going to ruin for want of hands to work it. Notwithstanding the lack of laborers for the cane-field, there were quite a large number of retainers about the place, wood-cutters, gardeners, India-rubber hunters, &c., all more or less dependent upon the doctor, and, surrounded by them and their families and his own children, with a large library, and enough to live comfortably upon, he seemed to be very well contented with his lot, and although regretting the failure of his great enterprise, did not let it make him unhappy.

We passed the remainder of the day of our arrival and all the following in collecting such further information as was required. Mr. Menocal and myself went in a canoe some miles farther up the river. Thus far we found no point where a dam could be built, the banks being low and swampy. Occasionally high ground approached one bank or the other, but never on both sides at once. The banks were alluvial, except in the few cases already mentioned, and these were not met within fifteen miles of the mouth. Our soundings had shown from 25 to 30 feet of water in the channel for the first three miles from the mouth, then frequent bars with 10 feet, 8 feet, and finally not more than 4 feet, these growing more and more frequent and longer as we ascended the river. Just above Dr. Kratochvil's place we found a solid gravel bar some three-quarters of a mile in length, with scarcely water enough to float a canoe. Most of the others were composed mainly of mud, which is also deposited in large outlying flats off the mouth of the river. A strong tidal current at all times and overwhelming floods during the rainy season would render abortive any attempt to dredge a channel in this stream, while up to the highest point visited by us, as said above, no location existed for a dam by which to produce slack-water navigation. We concluded that further examination, except at the river-mouth, was unnecessary.

Desiring to know a little more of the harbor-bar, Mr. Menocal, Dr. Bransford, and myself, bidding good-bye to our hospitable host, Dr. Kratochvil, started in a canoe, at 3.30 on the morning of the 19th, for Boca del Bayano, which we wanted to reach by 8 o'clock (when the tide would be at the lowest, and also to take advantage of the usual morning calm). This, by the help of the ebb and by vigorous paddling, we accomplished. A very disagreeable trip it was, too, in the chill night-air. The banks of the river, left dripping and slimy by the falling tide, added to the unpleasant effect. The doctor administered to each of us and took himself a five-grain dose of quinine to ward off fever, which he thought we stood a good chance of contracting.

Arrived at the village of Boca del Bayano we set up a tide-gauge, which the doctor took charge of. Mr. Menocal and myself procured some fresh hands for our canoe and went out to the bar to sound. A pull of two hours against the incoming tide brought us to the bar, upon which we found a depth of but 12 feet (reducing to low water). The mud-flats, already spoken of, extended for several miles in each direction. The bar, which is said to be a shifting one (as is altogether probable from its character), lay at the time of our visit near the island of Chepillo, and about two miles from the mouth proper of the river.

Turning back, we encountered the land-breeze, now quite brisk, and a little toppling sea made by its opposition to the incoming tide. Our pull back to the beach consumed another two hours. We were drenched to the skin before we landed, and hungry enough not to criticise the breakfast prepared for us by the wife of the alcalde. We had not had time to breakfast before starting for the bar.

Toward evening Paymaster Clark joined us with the schooner, and we embarked for Panama, where we arrived at midnight on the 20th.

Regarding the route from the mouth of the Bayano to the Gulf of San Blas, two careful surveys, one under the auspices of Mr. Frederick W. Kelley and others, of New York, in 1864, and one by the expedition under Commander T. O. Selfridge, U. S. N., in 1870–'71, have shown that between the Gulf of San Blas and the Pacific slope of the Cordillera a tunnel will be required of not less than seven miles in extent for a thorough cut. By using a higher summit-level, *i. e.*, resorting to locks, the length of the tunnel might be somewhat reduced, possibly to six miles, and still have feed-water, though this is by no means certain. The cost of a tunnel of suitable cross-sections, with

masonry-arch, and of one mile in length, Mr. Menocal computes to be not less than $15,000,000, while for greater lengths the cost would be increased in a very rapid ratio, owing to the distance it would be necessary to transport material excavated and that used in construction. It is not, in my opinion, safe to estimate for self-sustaining rock in a projected tunnel of so large dimensions, for, although it might prove to be so, there is no means of ascertaining the fact beforehand, and the chances are, to say the least, as much against as for it. A tunnel of even five miles in length would thus cost between $80,000,000 and $100,000,000. The Bayano River cannot be utilized, and an independent canal would have to be built from the end of the tunnel to the sea. The line possesses but two good features, one the magnificent harbor afforded by the Gulf of San Blas, the other the short distance from sea to sea, in a direct line but thirty miles. These, however, compensate but slightly for the enormous disadvantages. The line bears no comparison with either the Nicaragua route or that of Panama as developed.

On our return I found a letter awaiting me from the department, forwarding a copy (appended and marked A) of a communication from a Mr. Julian Sucre, of Aspinwall, referring to a plan for a passage across the Isthmus. I called upon Mr. Sucre, and found his plan, as I had supposed, one which had been offered some years since by a Captain Hugg, a master of a coaster, to Commander Selfridge. Commander Selfridge was satisfied at the time that Captain Hugg had no information which he could not procure in better shape by actual survey. Mr. Sucre, who proved to be the husband of Captain Hugg's daughter, showed great reluctance in giving me information in regard to the line, notwithstanding he so freely offered it in his written communication, evidently desiring first to make some definite arrangement as to compensation. He, however, admitted that the route began in the Gulf of San Blas, admitted that he had never seen it, and that he had no information in regard to it beyond a traverse, *i. e.*, a line of compass-courses and the corresponding distances, the following of which from the starting-point, which he thought he should be able to recognize, would give the location of the line. He also stated that the line, though but eighteen miles long, was from sea to sea.

He also acknowledged that Captain Hugg had no instruments, beyond those used in navigating his vessel, for making the survey. He expressly declared that the river Bayano did not form part of the scheme. This was the amount of the information I was able to extract from the gentleman, and it was quite sufficient. To begin with, the distance from sea to sea in a direct line is thirty miles, approximately, at the narrowest part of the Isthmus. This we have from the marine charts, which are fairly accurate. Information obtained in the manner that Captain Hugg professed to have obtained his, *i. e.*, by merely walking over it, has been proved repeatedly to be absolutely worthless. A man who walks over a trail for fifteen or twenty miles has very little idea of what heights he has passed over; if his path carries him over a steep-sided hill he is apt to exaggerate the height of it, but if the ascents and descents are very gradual, he will often believe that he has been upon an almost dead level. Even very intelligent persons will be deceived in such cases. Dr. Cullen, whose name was for years so prominently connected with the Darien route, asserted, and probably believed, that he had crossed the Isthmus from Escoses Harbor without finding an elevation of over 150 feet. An instrumental examination by a party under his own guidance found over 1,000 feet of elevation.

Captain Hugg's route was clearly no other than the San Blas line, the impracticability of which, to my mind, had been thoroughly demonstrated.

PROGRESS OF THE PANAMA SURVEY.

On communicating with our parties in the field, we found that during our absence they had been making good progress in their work.

Lieutenant Colby had shifted his camp on March 16 to Lion Hill, and again on the 20th to Gatun, occupying at each place, by consent of Superintendent White, the station residence.

Lieutenant Leutzé had shifted to a place near Gorgona on the 19th, calling his encampment "Camp Colby."

On the day following our return I was seized with an attack of fever, which confined me to my quarters for nearly a week. Mr. Menocal, however, nothing worse for his trip, went into the field

again at once. Lieutenant Leutzé was suffering from frequent attacks of the fever, but, refusing to spare himself, continued his work to the end, and has suffered for it ever since.

The officers were now making great efforts to complete their lines in time to sail for home in the steamer of the 4th of April, and for this purpose were performing an amount of work which would have broken down the strongest, had it continued. Mr. Colby, wishing to communicate with myself concerning his line, and finding that I was unable to visit him, walked into Aspinwall, a distance of seven miles, one evening after having worked from early daylight until 4 o'clock in the afternoon in a heavy swamp. He then started back, and walked nearly to his camp before procuring a horse upon which to ride the remainder of the distance.

March 24, Mr. Leutzé again struck his tents and shifted to a point near Mamei, calling his encampment "Camp Jeffers," for the Chief of the Bureau of Ordnance of the Navy.

On the 26th Mr. Colby shifted to Empire station, to make some further examination near that point, where, after plotting, it had been shown that the line could probably be improved. On the 31st, having completed this work, he returned with his party to Gatun.

On the 29th, Mr. Leutzé again shifted camp to San Pablo station, occupying, for the first time, one of the station residences, instead of his tents.

On the 1st of April, Mr. Leutzé's line intersected that of Mr. Colby near the initial point of the latter, and Lieutenant Very connected his traverse with Lieutenant Taussig's original station-mark. On the following day, Messrs. Coffin and Green brought up the levels and connected with Mr. Moser's bench.

April 2, Mr. Colby's line reached the beach at Aspinwall, he having been delayed one day in trying to improve on a portion of the line near Lion Hill, where, after plotting, it had been found necessary to have a little further information.

The natives were now discharged, and the officers and their assistants, with their camp equipage, proceeded to Aspinwall. Here what remained of the provisions brought from the United States and such articles of outfit as were not thought worth transporting back to New York were sold at auction.

The expedition was then embarked on board the Pacific Mail steamship Acapulco, and sailed for home on the 4th of April, arriving in New York on the 12th of the same month.

It is impossible, in a brief account like the foregoing, to give any adequate idea of the amount of labor performed by the officers and men upon a survey of this character, and only those who have had experience in tropical forests, with their dense vegetable growth, the jungle of vines, undergrowth, briars, canes, grasses, the numerous varieties of plants bearing thorns, &c., and who have experienced the annoyance of the myriads of insects, particularly the *garapata*, or wood-tick, which infests seemingly almost every leaf that one brushes against, can fully appreciate the character of the undertaking. And too much cannot be said in commendation of the officers for their untiring zeal and energy, and for the cheerfulness with which they encountered discomforts and difficulties. The severest labor, as well as the chief responsibility, in the parties rested upon the commanding officers, Lieutenants Leutzé and Colby. Upon them devolved the immediate conduct of the survey, the control of the men, and the general comfort of the parties; and each showed himself to be entirely equal to the requirements of his position. Lieutenants Very and Taussig, in addition to running the transit instruments, were required, as is usual, to sketch in the topography. Lieutenant Moser, Messrs. Coffin and Green, ran the levels, and on connecting their several sections and referring their results to the plane of mean tide, found their accumulated error to be less than one-half foot. Dr. Bransford, in addition to taking care of the sick, made some very valuable collections in natural history. He also made a collection of geological specimens, which will pretty completely exhibit the character of excavations and of available materials for construction. The services of Mr. Menocal, the chief engineer, were simply invaluable. With a thorough knowledge of his profession, full of resources in overcoming impediments, untiring in field-work, he moved from party to party as his assistance was needed; made constant reconnaissances ahead of the line, and thus saved the parties a great deal of useless work, and thereby hastened the completion of the survey. Messrs. Buck, Westerfield, Burnett, Fleming, and Philp were faithful and intelligent in the performance of their several duties.

WATER-SUPPLY.

By the plan which we propose for the construction of a canal (see map, Plate I), the water-supply will be drawn entirely from the river Chagres, not counting for the present the influx from springs or that which will be received from two small rivulets received into the canal by cess-pools. It will be carried to the receiving-basin of the canal by means of a feeder, to be described further on.

Gauges of the Chagres, taken with great care, showed that the amount of flow at the point where the proposed feeder leaves the river is about the same as that at the site of the viaduct.

On the 15th of March, the Chagres being at the time at an unusually low stage even for that season of the year, there was found a discharge of 55,900,800 cubic feet per day. Allowing eighty lockages a day—*i. e.*, forty ascending and forty descending—there would be required, without allowing for the displacement of the vessel in descending, which we have the right to do, making the loss just so much less, 34,400,000 cubic feet per day; adding 100 per cent. for waste, leakage, evaporation, and filtration—a very large allowance—we should still have an excess above the highest possible demand of about 9,000,000 cubic feet per day, supposing the supply to come from the feeder alone; a large percentage of the water needed would doubtless be supplied by springs. A well standing at the summit of the railroad, 142 feet above the proposed level of the canal, was full up to the surface during the driest period of our stay upon the Isthmus. While, therefore, I believe that all loss of water will be more than supplied from sources other than the river, the quantity from the latter source, as shown above, would be ample if such were not the case. It will be shown in the description of the feeder in what manner it is proposed to get rid of the superabundant waters at high stages of the river.

LOCATION OF THE CANAL.

For reasons already given, it had been determined to cross the river Chagres near the great bend at Matachin, and a short distance above the confluence of the Rio Obispo. (See map, Plate I.) The reasons for selecting this point may be briefly summarized as follows:

1st. The near approach of the two ranges of hills inclosing the valley of the river gave good abutments for the viaduct, at the same time giving ample room for a sufficient number of culverts to discharge the waters of the river in times of freshets.

2d. The valley of the Obispo gave a direct and favorable approach to a depression in the divide, passing which the valley of the Rio Grande carried the line by the shortest distance to the Bay of Panama.

3d. The level of the highest water-marks at this point were found to be 78 feet above mean tide of either sea. Adding to this the necessary rise of arch of the culverts, the thickness of wall in the viaduct over the crowns of the arches, and the proposed depth of water in the canal of 26 feet, would give a total of 123.75 feet as the height of the water-surface in the viaduct above that of mean tide. To descend from this height to the level of the sea would require twelve locks of a side, or twenty-four in all—the greatest number thought admissible, the number required in the Nicaragua line being but ten of a side. To go higher up the river would not only involve a greater number of locks, but would also involve going a greater distance for the initial point of the feeder, or else a higher dam. To go lower down the river, and consequently diminish the summit-level, would of course increase the length of the deep cut through the dividing ridge between the Atlantic and Pacific slopes.

THE VIADUCT.

The proposed viaduct will be 1,900 feet in extreme length; the water-way will be 65 feet wide and 26 feet deep; the side walls 23.25 feet thick at the bottom and 6 feet thick at the top; the thickness of the bottom wall over the crowns of the arches will be 6 feet. Twelve culverts are provided for, with 90 feet span each, and varying in height from the foundations of their respective piers from 40 feet to 12 feet, according to location.

The spring of the arch in each culvert begins at the highest water-mark. The rise of arch is 12.857 feet; the radius of the arch, 85 feet; the width of the piers at their heads is 111.5 feet; their

thickness, 25 feet; the area of each pier-head is consequently $111.5 \times 25 = 2,787.5$ square feet. Allowing 40 tons to the square foot, these will each sustain 249,760,000 pounds weight.

Mr. Menocal computes the actual weight to be borne as follows:

	Pounds.
Concrete: 254,300 cubic feet, at 150 pounds per cubic foot	38,145,000
Water: (65 feet width of water-way; 115 feet spread from center to center of arches; 26 feet depth; at 62.5 pounds per cubic foot) $65 \times 26 \times 115 \times 62.5$ equals	12,146,875
Total	50,291,875

or about one-fifth the sustaining power of the pier.

THE CANAL.

It is proposed to make the surface-level of the water in the viaduct the summit-level of the canal.

PACIFIC DIVISION.

From the end of the viaduct the proposed line leading to the Pacific extends in a general direction of south 37½° east through the range of hills inclosing the valley of the Chagres, passing which it enters the receiving-basin, of which a description will be given when treating of the feeder.

Leaving the basin, the same course is continued for a distance from the initial point of 1,323 feet; thence the general course is south 32° east for a distance of 27,239 feet, which brings the line to the summit-curve; thence south 50° east 39,565 feet; and finally on a general course of south 80° east 11,376 feet, which brings it to the beach, about one-quarter of a mile to the eastward of the Panama Railroad Company's wharf at Panama. The total length of the Pacific division is 79,509 feet, or 15.8 statute miles. These various sections are made up of straight reaches and of curves (see table, page —), which are arcs of circles; the general course given in each case being the bearing of one end of the section from the other.

The line is laid down to follow as nearly as possible the best, *i. e.*, the lowest profile; it occupies the valley of the Rio Obispo until the foot of the dividing range of hills is reached; crosses the divide through a depression somewhat to the eastward of the point where the railroad crosses; thence descends into the valley of the Rio Grande to the end of section 3, as above given, where it curves to the left and again to the right, finally reaching the point of debouchment. The straight reaches and the curves are numbered consecutively from the Pacific to the Atlantic. A table (No. 1) is herewith appended giving the lengths of the straights and curves (the length of the arc in feet in the latter case), the radii of the curves, the number of degrees of arc, the total distance from the Pacific terminus, and the middle ordinate for 400 feet in each curve. Practically, this last gives the distance of the middle of the keel of a ship 400 feet in length from the axis of the canal, when her bow and stern are exactly in the axis, in one of these curves.

Two small tributaries of the river Obispo are passed under the proposed canal by means of culverts, their beds being sufficiently low to admit of it.

One very small rivulet is received into the canal by means of a cess-pool. Short bends in the Obispo are occupied by the line of the canal in three localities, and a new channel in each case is provided for the stream.

At the foot of the divide, the Obispo itself, now diminished to a mere thread, is also received into the canal by means of a cess-pool. Descending into the valley of the Rio Grande, the present channel of that stream is crossed in several places, new channels being provided for in each case.

A drain is located leading into the Bay of Panama to the eastward of the debouchment of the canal, by which the waters of all the small streams coming now into the Rio Grande from the eastward will be discharged, while those coming in from the west will find vent through the present mouth of the Rio Grande.

Twelve descending locks, each with a lift of 10.3 feet, and one tide-lock with a lift of 10 feet, will be required in this division. All are favorably located. Nos. 4 and 5, Nos. 6, 7, 8, and 9, are in flights, and No. 12 and the tide-lock are also placed together. All the locks in this section, with the exception of Nos. 10 and 11, are located in hills to secure a natural rock foundation. Nos. 10

and 11 are in earth. The deepest or exact summit cut in this division will be 170 feet above the surface of the water; this is for a distance of only a rod, however, the profile falling rapidly on either side.

The total length of the summit-cut is 4.81 miles, and the average depth of cutting 76 feet above the proposed water-surface. The excavation for the remainder of the division will be but little more than the prism of the canal itself.

ATLANTIC DIVISION.

The following are the courses and distances of the several sections of canal from the viaduct to the Atlantic terminus, the courses in each case being, as before, the general direction, while the distance is the actual length of the straights and curves, viz:

	Feet.
From the viaduct north 37½° west	2,415
Thence north 86° west	19,639
Thence south 81° west	8,758
Thence north 50° west	9,471
Thence north 23° west	14,870
Thence north 57½° west	38,680
Thence north 28½° west	18,879
Thence north 17½° west	23,843
Total length of Atlantic division	136,550

or 25.9 statue miles. Total distance from sea to sea, 41.7 miles.

For a distance of 7.6 miles from the viaduct the country is very broken; several hills are passed; the line, however, following the best profile attainable. The longest cut will be 2,500 feet. The intermediate valleys offer ample places of deposit for the material excavated; much of it, indeed, being required for embankments. The line now falls into the valley of the Chagres, and is located in low and occasionally swampy land for a distance of 3.7 miles. Here the excavation will be less than the prism of the canal, the material excavated being used in constructing embankments. Hilly country is then met for about the same distance, after which the line continues in low, swampy ground to Aspinwall Bay.

Thirteen culverts are provided in this division; some for the passage under the canal of small streams, others to give vent to what water there might be in the rainy season in what were dry ravines at the time the survey was in progress. Two or three other little branches are turned into side-drains. Near Gatun the line occupies the present bed of the Chagres, for which a new channel is provided. The river Gatun, a tributary of the Chagres, is turned into the Mindi, and the Mindi into the Boca Chica, which discharges into Aspinwall Harbor about one mile outside the proposed debouchment of the canal. Twelve locks will be required, each with a lift of 10.3 feet. These are all located in hills. Locks Nos. 2, 3, and 4, Nos. 5, 6, 7, and Nos. 8 and 9, are in flights, respect ively. The line of the proposed canal is at no point more than a mile distant from the track of the Panama Railroad.

The prisms of the canal are in earth, rock, and swamp, as follows, the depth being throughout 26 feet, viz:

	Width at bottom.	Width at surface.	Slope of bank.
	Feet.	*Feet.*	
Earth	72	150	1 vertical to 1½ horizontal.
Rock	72	126	1 vertical to ½ horizontal.
Swamp	60	164	1 vertical to 2 horizontal.

These prisms are thought to be ample, even after allowing for the irregularities of excavation, for all purposes of navigation. Ten feet above the water-surface there is a berm on either side of 9 feet, forming a roadway; the same slope is then carried to the surface. In swampy land the banks are, of course, formed by the material taken out.

LOCKS.

The dimensions proposed for the locks are: total length, 500 feet; length between miter-sills, 450 feet; width of chamber, 65 feet. The design of the locks, made by Mr. Menocal, has been fully described in the report upon the Nicaragua survey. They are fed through 60′ side pipes, communicating with the lock-chambers by means of ports, three of a side, one at the head, one in the middle, and one at the foot of the chamber. It is proposed to use hydraulic concrete as dimension-stones, except for miter-sills, for which dressed stone is proposed and estimated for.

Nos. 10 and 11, in the Pacific division, are so located that there will probably be no rock foundation. For these there are proposed a concrete floor of 6 feet thickness; concrete side walls, with a thickness at the base of 30.95 feet, the inner faces to have an outward slope of $\frac{1}{4}$ foot horizontal to 1 foot vertical; on the outside the side walls to diminish in thickness by offsets of 3.66 feet each, four in number, and at equal distances from the bottom, the walls to be 6 feet thick at the coping.

Nos. 4, 7, 8, 12, and the tide-lock in the Pacific division, and Nos. 1, 2, 5, 6, 7, and 8 in the Atlantic, are believed to be located entirely in rock. For these a lining of concrete is estimated for, the floor to be 2 feet in thickness and the side walls 3 feet.

The other locks are believed to be partly in rock and partly in earth. For these is proposed a floor of concrete 2 feet thick and side walls 3 feet thick at the top of the rock, and increasing thence to the bottom of the chamber in the ratio of $\frac{1}{4}$ foot to 1 foot of descent. Above the rock, the side walls to be of concrete, and in dimensions identical with the corresponding portions of those in Nos. 11 or 12, Pacific slope, already described.

The turning-gates proposed are of the same character as those used in the United States naval dry-docks.

DRAINAGE.

One of the most vitally important questions to be considered in discussing the subject of the construction of a canal across the American Isthmus is that of drainage; and, singularly enough, among European writers upon the subject scarcely any attention has been given to it. Taking the Suez Canal as a standard for comparison, they almost without exception cling to the idea of a canal without locks; in other words, a cut down to the level of the sea. Such a channel would be burdened not only with the discharge of the springs developed in the cut, and whose number and force in a land so saturated with moisture would be beyond comparison with those of any hitherto constructed work, but must also become the ultimate drain of the surface of a very considerable portion of adjacent territory. It would, during the rainy season, if not indeed at all times, be a wild torrent, unfit for the passage of ships, and must speedily become filled with bars and other obstructions from the detritus furnished by its own current. It is a matter for congratulation, therefore, and not for regret, that in all localities so far examined the profiles are such as to make a canal without locks practically impossible. In this line, holding these facts in view, the proposed canal has been so laid down with reference to the actual profile (see Plate II), that in all sections of the work, except the tide-water reach at either end, natural drainage is provided into the valleys of the adjacent streams during the progress of construction, and subsequently through the canal itself, by simply cutting off the feeder and opening the gates below, if necessary, to empty the canal for examination or repairs.

Culverts have been provided, as already enumerated, for every stream, dry water-course, and ravine whose bed was sufficiently low to pass it under the canal. In the accompanying Plate II, each culvert is shown in elevation.

Side drains, also, already enumerated, are provided for those streams favorably located for that purpose, with a cross-section proportionate in each case to the discharge of the stream or streams which they are intended for.

In Table No. 2, hereunto appended, are given the names, if any, location, number, and dimension of spans, and the length of canal drained by each culvert, and the length drained by the various side drains.

No. 1.—*Table of straights and curves.*

PACIFIC SIDE.

From viaduct to Panama.

Straight.	Curve.	Radius.	Angle.	Length.	Total distance from initial point.	Middle ordinate per 400 feet.
		Feet.	° ′	*Feet.*	*Feet.*	*Feet.*
1				2, 490		
	1	5, 000	52 5	4, 546	7, 036	4
2				1, 815	8, 851	
	2	5, 000	58 00	5, 062	13, 913	4
3				14, 320	28, 233	
	3	10, 000	3 30	611	28, 844	2
4				7, 020	35, 864	
	4	20, 000	13 30	4, 538	40, 402	1
5				1, 240	41, 642	
	5	20, 000	7 05	2, 723	44, 365	1
6				4, 640	49, 005	
	6	5, 000	11 50	1, 030	50, 035	4
7				910	50, 945	
	7	5, 000	13 12	1, 152	52, 097	4
8				1, 580	53, 677	
	8	5, 000	16 45	1, 462	55, 139	4
9				4, 325	59, 464	
	9	10, 000	6 30	1, 134	60, 598	2
10				1, 610	62, 208	
	10	5, 000	26 10	2, 283	64, 491	4
11				12, 370	76, 861	
	11	10, 000	13 10	2, 646	79, 507	2

Total distance from viaduct to Panama, 15.06 miles.

ATLANTIC SIDE.

From viaduct to Aspinwall.

12				1, 640		
	12	2, 500	35 30	1, 550	3, 190	8
13				2, 660	5, 850	
	13	5, 000	17 20	1, 512	7, 362	4
14				7, 750	15, 112	
	14	2, 500	27 15	1, 209	16, 321	8
	15	2, 500	28 45	1, 253	17, 574	8
15				4, 480	22, 054	
	16	5, 000	21 00	1, 832	23, 886	4
16				2, 470	26, 356	
	17	5, 000	21 06	1, 840	28, 196	4
17				775	28, 971	
	18	5, 000	42 05	3, 672	32, 643	4
18				7, 635	40, 278	
	19	10, 000	47 20	8, 260	48, 538	2
19				2, 420	50, 958	
	20	5, 000	48 00	4, 190	55, 148	4
20				8, 265	63, 413	
	21	10, 000	8 25	1, 483	64, 896	2
21				7, 467	72, 363	
	22	10, 000	31 36	5, 515	77, 878	2
22				820	78, 698	
	23	10, 000	32 00	5, 550	84, 248	2
23				9, 580	93, 828	
	24	2, 500	57 15	2, 498	96, 326	8
24				2, 065	98, 391	
	25	5, 000	30 00	2, 618	101, 009	4
25				9, 080	110, 089	
	26	5, 000	60 00	5, 236	115, 325	4
26				8, 590	123, 915	
	27	10, 000	16 30	2, 880	126, 795	2
27				1, 175	127, 970	
	28	5, 000	47 40	4, 160	132, 130	4
28				4, 420	136, 550	

Total length from viaduct to Aspinwall, 25.86 miles.

TABLE No. 2.—*Culverts, side drains, &c.*

No. of culverts.	Name of river or ravine.	Location.	No. of spans.	Length of spans.	Rise of arch.	Height of pier.	Length of canal drained.
							Feet.
1	Ravine	C. 12, center	3	75	13	......	2100.
2	Ravine	S. 13, com	1	100	16	14	2800.
3	Ravines	S. 14, com	3 3	60 75	15 25	11 13	3800.
4	River near Gorgona	....	1	100	17	14	1800.
5	Ravine and Rio Juan Grande	S. 14 and C. 14	3 3 1 1 3	75 75 81 81 40	15 17 14 14 6	....	5400.
6	Rio Pisco and ravines	S. 15, mid	3	75	13	......	6100.
7	Gullies	....	1	81	14	......	5300.
8	River near Barbacoas	S. 18, com	3 3	75 75	13 13	....	5600.
9	Frijole Grande	C. 19, com	3	40	6	......	4400.
10	Frijole	S. 19, end	1	81	14	......	15800.
11	Rio Agua Salud	S. 20, end	3	60	9	......	7400.
12	Ravine in very broken country	S. 20, end	1	60	9	......	2200.
13	Qua. Aujeta	S. 21, com	3	75	17	......	6800.
14	Rio Tortuoso	C. 22	3 3	75 75	17 17	....	5800.
	Rio Gatun drains into Mindi Rio Mindi drains into Boca Chica	....	.....	.....	.....	......	58600.
	Viaduct Rio Chagres near Matachin	....	12	90	12. 8	12 to 44	3200.
	Basin near Obispo station	....	.....	.....	.....	......	2400.
1	Rio Cabulla	....	1	81	14	......	3000.
2	Near 40-foot falls	....	3	75	17	......	5700.
	Rio Sardanilla; well into canal	....	....	.....	.....	......	6800.
	Upper Obispo; well into canal	....	....	.....	.....	......	12900.
	Rio Grande drained each side of canal	....	.....	.....	.....	......	50800.

THE FEEDER.

The manner of locating the feeder has been already given.

At a point distant some twelve miles by the traverse above the site of the viaduct the valley of the Chagres was found to be inclosed between two solid walls of rock, very steep-sided, and approaching within less than 600 feet of each other.

Here a location was selected for a dam, by which to raise the waters of the river to a height of 12 feet (being one foot for each mile of distance) above the proposed surface of the water in the viaduct. The exact spot chosen was at a short bend made by the stream in its narrow valley. The channel-way is but 140 feet wide, with a rocky bank and bed; it is proposed to place the dam across the lower side of the bend, and across the channel from side to side of the valley, raising the waters 36 feet above the surface, as it stood at the time of the survey.

An admirable foundation and admirable abutments are secured for it by this location. In the accompanying drawing (Plate II) is shown the cross-section of the river-valley, together with the dimensions of the proposed structure.

As has been said, the initial point of the feeder is some 4,800 feet by the river-traverse above the site of the dam, but, owing to a curve in the river, quite as near to the line of canal. The effort to locate the feeder on a grade-line, by which an open cut of moderate depth could be secured, proved unavailing, except by a vast increase in the length, and even when the grade could be followed the hill-sides were frequently so steep as to give no location. The elevations were often much too high, and in two localities considerably too low for the purpose.

As finally located, the feeder proposed is 10.22 miles long, in which distance there will be required seven sections of tunnel of the following lengths, respectively, viz:

	Feet.
No. 1	4,200
No. 2	5,600
No. 3	300
No. 4	800
No. 5	1,400
No. 6	900
No. 7	500
Aggregate of tunnel	13,700

There will also be required two inverted siphons of 4,530 feet and 12,000 feet length, respectively. Computations were also made for aqueducts in place of the inverted siphons, and the cost found to be so little in excess, that Mr. Menocal strongly recommends their use instead. The remainder of the distance will be in open cut.

The feeder discharges its waters into a receiving-basin of 22 acres superficial area, and of which mention has already been made. This basin is located in the Pacific division about 1,000 feet from the end of the viaduct, and is formed by the erection of a dam to inclose an angle between two spurs of the range of hills forming one side of the valley of the Chagres. The length of the dam will be upon the top 1,760 feet; its height from the lowest foundation will be 74 feet. The channel of the Rio Obispo has to be turned for a short distance to give room for the dam.

A plan of the basin, with a profile showing the location of the dam and a cross-section of the latter, is among the accompanying drawings.

It is proposed, by a gate at the head of the feeder, to cut off the supply of water in the canal when found desirable. All the superabundant waters of the Chagres will then escape over the dam and will pass through the culverts under the viaducts.

The floods of the Chagres are caused in part by the backing up of the waters from below. Much of this could be prevented by clearing off the timber in the bends of the river; a work, by the way, which it would well repay the railroad company to undertake, the road suffering a good deal at times from being overflowed.

CHARACTER OF EXCAVATIONS AND MATERIALS FOR CONSTRUCTION.

In the valley of the Rio Grande the land is generally low and swampy; the soil seems to be an admixture of sand and clay, with a great deal of ooze in the bed of the stream.

Approaching the divide, we find a vegetable mold overlying a stratum of clay, with sandstone cropping out so often, and appearing in the cuts to be so near the surface, that in our computations for excavation we have taken the rock to be within 10 feet of the surface, not only in the dividing ridge, but in all the hills throughout the line. In the valleys 20 and 30 feet were allowed for earth. The sandstone is being quarried on the Pacific slope at Paraiso, about nine miles from Panama, and at Bohio station, on the Atlantic side, and seems to be of the same character in both places; so soft, that with a geologist's ordinary hammer I have broken to fragments pieces a half cubic foot in size with but two or three blows. Exposed to the atmosphere, it becomes honey-combed upon the surfaces. It is used by the Panama Railroad Company in bridges, &c., but would not be at all suitable for structures required to sustain great weight or to withstand any severe shocks.

The excavation in the hills and the higher valleys and plains will present only the ordinary features of vegetable mold overlying clay, and under that the sandstone, which last can be removed by the pick and crow-bar, though it would probably not be as economical a method as blasting. Some of the swamps, particularly what is known as Miller's Swamp, some twelve miles from Aspinwall, gave great trouble to the railroad company, and I fear would do so again in the event of the construction of a canal on this route.

The soil is a soft ooze of unknown depth, and I greatly fear that it would be exceedingly difficult to prevent the channel's filling up as fast as opened. Near Aspinwall the swamp seems to overlie a bed of coral, and a channel could probably be there maintained without trouble.

MATERIALS FOR CONSTRUCTION.

There is very little material, except timber, fit for purposes of construction. No rock was found which could be used as dimension-stone, and it is even doubtful whether any would answer for concrete.

Some limestone of fair quality was found near Empire and along the banks of the Chagres. Of timber, there is great abundance.

HARBORS.

Panama.—The only improvement proposed in the bay of Panama is the excavation of a straight channel 18 feet deep at mean low water out to the 18-foot curve, a distance of 9,200 feet. As there

are some 20 feet of rise and fall of tide, this channel would have 26 feet of depth whenever the water was above half-tide, or for over twelve hours each day.

Large vessels, or vessels of 18 feet draught and over, would have to wait for a favorable stage of the tide to enter or leave the canal, making a delay in extreme cases of from five to six hours.

The enormous additional cost of giving a deeper channel we regard as a worse evil than any small delays to ships in passing. The waters of the bay are so very quiet, that no protection is needed for the entrance of the canal.

Aspinwall.—Estimates have been made for deepening a channel in the Bay of Aspinwall out to the 26-feet curve, a distance of 1,826 feet, the few inches of rise and fall of the tide offering no such help as we have at Panama.

A breakwater is also estimated for, to extend from the point where the light-house is located in a west direction for a distance of 1,500 feet, which would render the harbor perfectly safe in all weathers.

The breakwater, although exceedingly desirable, is not absolutely necessary, and its construction might at least be delayed until the canal should begin to earn something.

The shores surrounding the Bay of Aspinwall are of coral formation, and all the reefs in the harbor seem to be of the same.

COMPUTATIONS AND ESTIMATES.

Careful computations have been made by Mr. Menocal, and by Lieutenants Taussig and Moser and Masters Coffin and Green, under his immediate direction, of the amount of excavations in rock and earth, of materials, masonry, &c., required for the construction of the canal, the erection of locks, dams, &c., for the improvement of the channels from the termini of the canal to deep water in the Bays of Panama and Aspinwall, respectively, and for a breakwater in the latter. And upon these computations Mr. Menocal has estimated the cost of the work.

The following is a summary of the estimated cost, viz:

Excavations and embankments	$37,392,935
One tide-lock, Pacific side	290,815
Twelve lift-locks, Pacific side	3,931,672
Twelve lift-locks, Atlantic side	3,787,286
Viaduct across the river Chagres	1,415,333
Feeder	7,954,182
Dam across the river Chagres	805,908
Dam to confine receiving-basin at Obispo	1,606,869
Fourteen culverts, Atlantic side	12,579,878
Two culverts, Pacific side	781,600
Drains, Atlantic side	921,073
Drains, Pacific side	368,638
Two wells, or cess-pools, to drain streams	13,886
Excavations, Bay of Panama	1,992,585
Excavations, Bay of Aspinwall	983,785
Breakwater at Aspinwall	782,673
Total	75,609,108
Adding 25 per cent. for contingencies	18,902,252
Total estimated cost	94,511,360

The following is the scale of prices allowed, viz:

	Per cubic yard.
Excavations in rock	$1 25 to $1 50
Excavations in earth	35
Excavations in swamp	40
Embankment	15
Hydraulic concrete	8 00
Dressed stone for miter-sills of locks	18 00
Excavation in tunnels for feeder, sandstone	4 00
Excavation in rock for cess-pools	4 00
Under-water excavation, Bay of Panama	5 00
Under-water excavation, Bay of Aspinwall	5 00
Pierre Perdue breakwater, Aspinwall	3 00 to 4 00

ADVANTAGES AND DISADVANTAGES OF THE PANAMA ROUTE.

The advantages of this line are: an ample water-supply; an open cut with but a moderate average depth of excavation; a comparatively short distance, 41.7 miles, from sea to sea; fair harbors on either side; the proximity of a well-constructed railroad; the established communication with the principal ports of the world; the absence of high winds; and, in common with the whole Isthmus, the fertility of its soil and the salubrity of its climate during the dry season.

The disadvantages are: the large annual rainfall; the want of material for construction purposes; the character of some of the swamp-lands in certain portions of the line; the amount of tunneling required in the feeder; the necessity of a viaduct; the prevailing calms of Panama Bay, causing tedious delays to sailing-vessels; and, finally, as compared with more northern lines, the greater distance of Panama* from the ports upon the west coast of the United States.

CLIMATE, HEALTH, ETC.

The year is divided, as in other parts of the American Isthmus and of Central America, into two seasons, the rainy and the dry, the former beginning in the latter part of May and lasting until the last of November, when it gives place to the latter, which lasts till May comes around again. There is comparatively little authentic data on the subject of the annual rainfall upon the Isthmus. During the last few years, careful observations have been made by the surgeon of the Panama Railroad Company at Aspinwall. His results are given in tabular form in the following paragraphs, copied from the Panama Star and Herald of April 7, 1875:

THE RAINFALL OF THE ISTHMUS.—We are enabled to present our readers with an interesting abstract from the records kept by the surgeons of the Panama Railroad Company at Aspinwall of the rainfall there for five consecutive years from 1869 to 1874, inclusive. It will be seen from the table of the monthly average of these years that the greatest quantity of rain falls on the Atlantic slopes and plains of the Cordilleras in the month of November, whereas on the Pacific side the month of October has always been regarded as the rainiest month in the year. It is to be regretted that no one has ever thought of keeping the rain-fall at Panama, by which an interesting comparison could have been made between the two places; but we have been able to obtain some statistics of the kind, kept at Taboga, an island about 10 miles to the south, which, though having a less rainfall than Panama, nevertheless enables an approximate estimate to be formed of that on the Pacific coast of the Isthmus as compared with that of the Atlantic. There is no doubt that, be the cause what it may, the rainfall of the Atlantic coast pours down a quantity of water along the Atlantic slopes of the Isthmus one-third more than ever falls over the plains or islands of the Pacific. We need only take as an instance the rainfall of 1863 at Aspinwall, which is recorded as 135.96 inches, while during the same year there fell at the Island of Taboga, only 48.51 inches, and this proportion more or less may be taken as a rough guess of the rain that falls at Panama compared with Aspinwall.

TABLE I.—*Annual rainfall at Aspinwall, 1869 to 1874.*

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
1869	.83	.77	.49	5.04	6.72	10.66	18.22	14.02	8.98	14.82	24.13	10.10	114.23
1870	4.30	3.33	4.95	6.46	20.95	12.48	15.60	16.35	6.74	11.21	32.42	14.85	149.64
1871	15.42	.53	.05	1.52	1.63	7.70	23.27	11.56	8.00	12.58	12.38	4.94	99.58
1872	3.57	.75	.83	1.30	21.43	22.00	19.90	19.97	16.20	.32	19.11	13.12	170.18
1873	6.33	.25	.13	2.18	3.92	13.20	12.50	10.69	10.91	14.30	11.77	.94	87.12
1874	5.33	1.34	3.94	18.02	8.92	15.87	13.62	17.28	8.22	16.65	20.62	7.89	137.70
Average	5.96	1.16	1.73	5.75	10.59	13.65	17.18	14.98	9.67	16.92	20.05	8.64	....

We insert the rainfall of each month for the year 1861, 1863, 1864, and part of the rainy season of 1866 at the Island of Taboga.

TABLE II.—*Rainfall at the Island of Taboga.*

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
1861	....	....	....	2.16	14.30	10.91	8.27	4.30	8.87	11.19	5.23	6.76	71.89
1863	....	....	....	0.26	1.60	8.80	8.11	9.54	11.94	1.62	2.87	3.77	48.51
1864	0.50	....	....	....	3.13	4.78	2.08	5.91	3.60	11.33	2.97	11.42	45.22
1866	....	....	....	....	....	....	....	8.74	4.90	5.16	5.12	4.30	30.22

*Panama is six hundred miles farther from San Francisco than Brito, the Pacific terminus of the proposed canal through Nicaragua.

It may be set down as a rule that for 16 inches that falls a month in Aspinwall there falls 3 inches in Taboga.

In the month of April, in Taboga, in 1861, we find there were slight showers of rain at the beginning of the month, which went on increasing as the month went on. The highest temperature was once 91° on the 14th and the lowest on the 26th, 74° Fahr. The solar radiation rose the blackened bulb thermometer to 115° at midway on the 3d, and once in the morning to 102° on the 26th. The mean of the ozonometer for the month was 2.06. During very heavy rains the ozone reaction was very little. A thermometer sunk in the earth two feet on the side of a hill averaged 80° for ten days.

If we take the month of May, in the same year, we find recorded the following meteorological observations. This month has been unusually heavy—22 days were rainy, the quantity falling being 14.30 inches, while during the first half of the month there only fell 2.19 inches. The ozone was also less than in the dry season months. The maximum of heat was 87° and the minimun 74°. The highest temperature in the sun was 101°, and with the terrestrial radiation thermometer 90°.

Observations on the rainfall at Panama at the end of last year gave for the latter half of the month of August 1.14 inch, for September 8 inches, and in October 17 inches; the same month at Aspinwall giving 16.65 inches and November 20.62 inches, while there was almost none at Panama.

The difference in the amount of rainfall upon the windward and leeward sides of the Isthmus, approximately stated in the above-quoted passages, is of course to be expected. Narrow as is the Isthmus at this particular point, the enormous precipitation on the windward side frees the atmosphere of a very large percentage of its moisture before it has crossed the high ground.

I do not regard the climate as an unhealthy one for temperate persons, who exercise the proper care in their diet and habits. The diseases, as I have had occasion to say in a former report, are few in number, simple in character, and generally yield readily to treatment, unless the patient be a dissipated person. The report of Dr. Bransford will be found interesting on this point.

In estimating the amount of labor which can be performed by a man in Central America, comparison is often made with the Southern States of the Union. This is hardly a fair example upon which to form a judgment. The trade-winds, blowing home for a large portion of the year, afford an element which the climate of our Southern States does not possess, and which greatly mitigates the heat, or at least the ill-effects of heat.

The temperature in the shade averages 82°, about, the year around, and the barometer 29.95 pretty nearly.

RIO INDIO COAL-MINES.

A short time before completing the survey the following order was received from the Navy Department:

NAVY DEPARTMENT,
Washington, February 9, 1875.

SIR: I inclose for your examination and report, should you have opportunity and if so doing will not interfere with your operations in connection with the survey of the Isthmus, printed documents on the subject of coal-mines on the Isthmus of Darien.

Very respectfully,

GEO. M. ROBESON,
Secretary of the Navy.

Commander E. P. LULL,
Panama, United States of Colombia.

Accompanying the above order were the following memoranda from the Rev. Richard Temple, who claimed to be part owner of the mines referred to:

To Commodore AMMEN,
Navy Department, Washington, D. C.:

SIR: The order from the department to Captain Lull was accompanied by a pamphlet containing all the necessary information respecting the Rio Indio coal-mines, belonging to Rev. Richard Temple and Capt. Daniel George.

Having already satisfactorily ascertained the great extent and excellent quality of the coal, fully detailed in the pamphlet, Mr. Temple is very anxious to obtain the opinion of the very competent civil engineer that accompanies Captain Lull, and to have his report incorporated in the report to the department of the result of the expedition, believing that it would enhance the probable success of the present exploration in completing the many advantages of this route over those already examined.

Mr. Temple desires to ascertain the best and cheapest way to work the mines and get the coal to market. In the dry season the easiest way to reach the mines is from Aspinwall along the coast southward to Puerto Condido, at the mouth of the Rio Indio, some thirty-three miles; then up the river, south and east, at a rough estimate, probably twenty miles farther. It is said that for nine months in the year the coal can be shipped, by flatboats, on the Trinidad and

Gatun, to Gatun station, on the Panama Railroad, in one day. It is important to ascertain this fully; also whether it would not be cheaper to carry the coal by tramway to a convenient point than by water.

The distance by Chorrera, on the Pacific, about twelve miles from Panama. From the streams dividing on the water-shed there is, according to the statement of the Indian guides, a distance of only eight miles, over a comparatively level country, to the mines. This would make the distance from Chorrera about the same as from Aspinwall. The ascertaining of all these points is desired.

The only persons that know the mines and can serve as competent guides are Capt. Daniel George and his grandson, Jacinto George, and Mr. F. C. Herbruger, of Panama.

From the pamphlet accompanying the memoranda I extract the following:

ASPINWALL (COLON), *April* 18, 1871.

At the request of the Rev. Richard Temple, I accompanied him to examine some coal-lands he had been fortunate enough to secure on the Isthmus of Panama. We crossed from the Pacific side to the Atlantic. The first portion of the journey was undertaken on foot, keeping the Indian trail through the forest, and frequently crossing rivers and streams and climbing mountains of considerable altitude. The latter part was performed either in canoes, going up and down the rivers, or walking through the beds of the streams, in some cases to their sources in the hills. In this way a good idea can be formed of the geological formations and characteristics of the regions through which we passed. I found the coal much richer and more extensive than had been represented to me by Mr. Temple. The first seam we examined was Uvero. The vein crosses the stream on which the mine is situated obliquely, and can be seen on each bank. In one place a large sandstone bowlder is lying on the top of the seam. The coal dips almost perpendicularly, and is about 12 feet thick. From this seam I obtained better specimens than any that were used in the trial at Aspinwall (Colon). We afterward traced this seam to various points on the same river, and then to another river at considerable distance.

The second mine we visited was Jaboncillo. The seam crops out on the banks of the Rio Indio. Here the coal is visible at two different elevations. It was here that we obtained the coal that was so successfully tested. In one place the stream runs over the coal for a considerable distance, the seam dipping at an angle of about fifteen degrees, and in the other case it runs along the side of the river for about one hundred yards, and then disappears under the water.

The third mine we visited was the Esterial. This mine is situated on the bank of a small stream that flows into the river Esterial, which empties into the Rio Indio. Near the small stream where the coal is found there rises a hill about 200 feet high. The coal, as seen on the opposite side of the stream, seems to run in the direction of Guinea, with the dip of sixty degrees; thickness about 9 feet. The last mine we visited was Guinea. Here the coal crops out in five distinct seams, separated by shales and clays, the depth of these deposits being more than 25 feet thick. From my own personal observation, and the statements of the more intelligent among the inhabitants, I believe there are large and valuable deposits of coal in the localities we visited.

With regard to the appearance of the coal, it resembles the cannel coal in many respects, being clean, almost pure carbon, breaking in two directions nearly at right angle in the surface specimens, and more irregularly as we got lower down, becoming harder and heavier as the distance increased from the surface and from the effects of the atmosphere. In view of the result of the trial at Aspinwall (Colon), on April 17, 1871, on 863 pounds of it, it is impossible to deny that it burns with a very clear hot flame, gives but little smoke, does not cake, and, though light, is very durable, producing no clinker and scarcely any ashes.

The great number of rivers intersecting the seams of coal present unusual facilities for working and transportation. As to its immense importance in a commercial point of view, I feel confident that the facts that have recently come to the notice of the residents on the Isthmus, and which will soon be made more fully known in other quarters, must greatly enhance its value.

CHARLES ENSOR, B. A., C. E.,
Trinity College, Dublin.

ASPINWALL, *April* 18, 1871.

Having accompanied the Rev. Richard Temple to the Isthmus of Panama for the purpose of examining and testing the coal that had been discovered there about three or four years since, I soon found that the statements made by him fell far below the reality. I found veins cropping in many places respecting which he had said nothing. We brought about twenty-five hundred pounds of coal with us to Aspinwall. Through the kindness of the Pacific Mail Steamship Company an opportunity was afforded of testing it on a stationary boiler connected with an engine employed in pumping water and hoisting. The fire was lighted under the boiler at five minutes past 1 p. m., and in thirty-five minutes the gauge indicated 25 pounds of steam. At 2, the boiler was blowing off with 55 pounds of steam, the furnace-doors being open. I find the coal very free from sulphur and iron. It burns freely with the doors of the furnace open, leaving but little ashes, and no clinker perceptible. Very light fires make flame equal to double the amount of Cumberland coal, with which I have been intimately acquainted for many years. To burn it economically requires but little draught, and I am of the opinion that a saving of one-third can be effected when the firemen have become acquainted with the best method of managing it. I have seen no locality where coal mines could be worked to a greater advantage. The seams are rich and extensive; the climate much healthier than at Aspinwall and Panama. There is a water communication with the Atlantic by the way of Rio Indio, on the banks of which the coal lies. For nine

months of the year this river is navigable, and for the remaining three months it could be made so at a very trifling expense. I have no hesitation in stating that this coal is better than any that I have tested taken from the same depth. This immense property, if properly developed, will inevitably prove of great benefit to these localities.

WILLIAM H. ARNOLD,
Civil Engineer.

Owing to the distance and inaccessibility of the mines in question, such an examination as was asked for by Mr. Temple, or, indeed, any examination, which would have added to the information already possessed, could only be made at considerable expense; and having already exhausted nearly the whole amount of funds available for the work, I contented myself with sending a trustworthy person to obtain a specimen of the coal for examination. This was submitted to the Smithsonian Institution, and was examined by Dr. F. M. Endlich, whose conclusions are given in the following letter:

SMITHSONIAN INSTITUTION,
Washington, D. C., December 6, 1875.

DEAR SIR: On the return, recently, of our mineralogist, the coal left by you for examination was at once placed in his hands, and the following is his report concerning it:

"The specimen is bituminous coal, somewhat resembling cannel. It was evidently taken from near the surface, therefore the determination of the water is of no value. Ash comprises about ten (10) per cent. of the entire weight. This coal may be considered serviceable for most ordinary purposes."

The above report may be fully relied on.

I am, very truly yours,

JOSEPH HENRY,
Secretary Smithsonian Institution.

Commander E. P. LULL, U. S. N.

CONCLUSION.

While this report was in progress, Mr. Menocal, the chief engineer of the expedition, was called away very suddenly to go to Nicaragua, upon a mission in which he is now engaged, under the government, and did not, I regret to say, make a report. He had, however, completed the estimates already given, and left his work in such condition that, although it would have been exceedingly interesting, no detailed report was actually necessary.

Since Mr. Menocal's departure, Lieut. E. D. Taussig, U. S. N., has been in charge of the completion of such matters as required it, and has exhibited the same close accuracy and attention that have characterized his work since his first connection with the expedition.

The maps, plans, and drawings have been prepared by Mr. James B. Philp, the draughtsman of the expedition, and are accurately and beautifully executed.

I have the honor to be, sir, your most obedient servant,

EDWARD P. LULL,
Commander, Commanding Expedition.

Hon. GEO. M. ROBESON,
Secretary of the Navy.

A.

NAVY DEPARTMENT, *Washington, March* 8, 1875.

SIR: The Department incloses for your information and consideration a copy of a communication from Mr. Julian Sucre, Aspinwall, referring to a plan for a passage across the Isthmus. This letter was transmitted to this Department by the honorable Secretary of State.

Very respectfully,

GEO. M. ROBESON,
Secretary of the Navy.

Commander E. P. LULL, U. S. N.,
Aspinwall, United States of Colombia.

B.

COLON, ASPINWALL, *January* 30, 1875.

SIR: I beg most respectfully to submit for the consideration of your government the fact that I hold in my possession the plan taken by the late Capt. John Hugg, of Baltimore, of a passage across the Isthmus of only eighteen miles, and which the deceased traveled over on three different occasions during his lifetime. This plan is the legacy left by the deceased to his children, and with whom I am connected. If the State Department deem it practicable to make use of it, the family have no objection, and, if consistent with the desire of the government, I would join the party on the survey; and, as I presume that route will be adopted for the proposed canal, then the family will expect to some remuneration will be given to them by your government.

I beg to inclose herewith a newspaper with some remarks on the subject in Spanish which may better explain this matter.

I have the honor to be, sir, you most humble servant,

JULIAN SUCRE.

The Hon. SECRETARY OF STATE,
United States of America, at Washington, D. C.

C.

[Translation.]

THE INTEROCEANIC CANAL.

We extract the following paragraphs from a letter which has been addressed to us:

"Capt. John Hugg, a North American citizen and native of Baltimore, who for nearly nine years past has been sleeping the sleep of death, bequeathed to his numerous family before he went down to the grave a legacy which was perhaps thought by them to be of very small value, but which, nevertheless, may serve to immortalize his name and greatly to advance the material progress of America, of Europe, and of the entire world.

"This legacy is nothing less than a route for the opening of communication between the two oceans, which is the result of the numerous observations made by Captain Hugg while crossing the mountains, which he did three times.

"A canal constructed by this route would be scarcely eighteen miles in length, and I am fully authorized by the family of the unfortuate navigator to state to all nations, particularly the United States of America, that if they think proper they may address me, and I will make all such arrangements as the case may require.

"It is by no means my desire to represent Captain Hugg as having been a highly scientific man, but only to praise his indomitable perseverance in the execution of so difficult an undertaking, which he accomplished in spite of innumerable obstacles.

"If the Government of the United States shall, as I hope it will, make an equitable arrangement with the Hugg family, and resolve to examine the route in question, it is more than possible that its long-cherished hopes and our brightest dreams will soon be realized.

"JULIAN SUCRE.

"COLON, *January* 16, 1875."

The accompanying documents are respectfully forwarded herewith, viz:

1. Journal of Lieut. E. H. C. Leutzé, U. S. N., in charge of party No. 1.
2. Journal of Lieut. H. G. O. Colby, U. S. N., in charge of party No. 2.
3. Report of Passed Assistant Surgeon John F. Bransford, U. S. N. Climate, Health, &c.
4. On the Batrachia and Reptilia collected by Dr. John F. Bransford, U. S. N., during the Panama Canal survey of 1875. Described by Professor E. D. Cope.

Very respectfully, your obedient servant,

EDWARD P. LULL,
Commander, U. S. N.

Hon. GEO. M. ROBESON,
Secretary of the Navy, Washington, D. C.

JOURNAL OF PARTY No. 1.

LIEUT. E. H. C. LEUTZÉ, U. S. N., IN CHARGE.

Aspinwall, United States of Colombia, January 18, 1875.—Commander Lull went to Panama. Shipped Henry Williams as servant. Engaged two sailmakers from steamship Acapulco. United States steamship Canandaigua came in. Paid official visit to commanding officer. Served out accouterments. Weather fine.

January 19.—Served out provisions and shipped them to Matachin. Shipped Charles Davis as servant for party 2. Received from Commander Lull, who is now at Panama, telegraphic orders to start to-morrow for Matachin, where he will meet the party, with a number of natives employed as *macheteros*.

January 20.—Shipped Joseph Ambrosio and James Boyd as cooks. At 7 a. m., all hands started in train for Matachin. The parties were divided as follows, viz:

No. 1.—Lieut. E. H. Leutzé, U. S. N., in charge; Lieut. E. W. Very, U. S. N., transit; Master J. H. C. Coffin, U. S. N., level; Henry Lisle Fleming, rodman; Charles A. Smith, Charles Arbeaud, chainmen; Mancel Philp, pole; Joseph Ambrosio, cook; Henry Williams, servant.

No. 2.—Lieut. H. G. O. Colby, U. S. N., in charge; Lieut. E. D. Taussig, U. S. N., transit; Master H. L. Green, U. S. N., level; John E. Buck, commander's clerk, U. S. N.; Robert S. Burnett, rodman; John H. Westerfield, chainman; James Boyd, cook; Charles Davis, servant.

Civil Engineer A. G. Menocal, U. S. N., and Passed Assistant Surgeon J. F. Bransford, U. S. N., accompanied the parties.

On arriving at Matachin found that Commander Lull had been detained in Panama. Hired a canoe and went up the river to select place for camp.

At 2.30, Commander Lull arrived, bringing 18 *macheteros* and a quantity of provisions. He then went to Aspinwall.

The *macheteros* were assigned to the two parties, 9 to each.

All the rodmen, *macheteros*, and several officers, all in charge of Lieutenant Taussig, slept at the railroad station of Obispo. Weather pleasant.

Camp Ammen, Chagres River, January 21.—Turned out at 3.30 a. m., hired four canoes for the day, and built camp on the left bank of the Chagres, about one mile from Matachin. Named it Daniel Ammen. Commander Lull and Paymaster Clarke visited the camp. Received from Gatun four canoes, hired by Commander Lull for use in the parties. Weather fine.

January 22.—Finished building camp and adjusted instruments. Sent canoe for Commander Lull, who went to Aspinwall after visiting camp. Mr. Menocal went to Panama with transit instrument of party 1, in order to have it repaired. Slight showers during early morning; otherwise fine.

January 23.—Parties commenced work on survey. This journal only records work of party 1. To this party was assigned the work of locating a feeder for the canal. Gauged river Chagres and found constant for current-meter. Commander Lull visited camp.

January 24.—Sunday. No work.

January 25.—Started to run line up the Charges, but work had to be suspended, as level tripod broke. Sent Master Coffin to Aspinwall to have it repaired. Dr. Bransford went to Panama. Mr. Gerald McKenny, of the New York Herald staff, visited the camp. Received mail. Fine weather.

January 26.—Mr. White, superintendent of the Panama Railroad, visited camp. Lieut. J. F. Moser, U. S. N., reported for duty, and was assigned to party No. 2. Commander Lull visited camp during afternoon. Mr. Coffin returned from Aspinwall. Dr. Bransford returned from Panama. Weather rainy in the afternoon.

January 27.—Continued work on the line; made 4,500 feet, mostly in the river.

January 28.—Extended survey 10,000 feet. Work all in the Chagres River and very hard, on account of strong current. Received provisions. Weather fine.

January 29.—The parties separated in the morning; party No. 2 moving to Empire station. Lieutenant Leutzé took one load of provisions up the Chagres and left it at the proposed camping-ground. Remainder of the party extended the survey 7,779 feet. Received provisions from Panama.

January 30.—Moved camp up the river. Found it to be hard and troublesome work, on account of rapids and shoals. Half of the party, in charge of Master Coffin, walked up by the river-trail. Master Green joined the party, having been transferred from party No. 2. Lieutenant Very named the camp Santa Margarita. Rain-squalls during the afternoon.

Camp Margarita, Chagres River, January 31, 1875.—Sunday. Finished building camp. Rainy during afternoon.

February 1.—Extended the line 10,861 feet, although the work was very hard. General character of river the same, *i. e.*, low banks with gravel beaches. The valley formed by the inclosing ranges of hills increasing in width.

February 2.—Ran 10,951 feet. Commander Lull visited the party.

February 3.—The day's work was 11,936 feet. At the termination, the character of the river changed. Banks steep, with isolated rocky places.

February 4.—Moved camp up the river. Mr. Coffin named it Washington.

Camp Washington, Chagres River, February 5.—Finished building camp. Lieutenant Leutzé went down the river to bring up provisions which had been left.

February 6.—Could not commence work until 7.30 a. m., as it rained earlier. Ran 4,056 feet up the river, and took a cross-section, which occupied a long time, as the hills on both sides were very steep. From the top of one of these hills it could be plainly observed that the river ran between two mountain-chains about 3,000 feet apart, washing the base of first one and then the other.

February 7.—Sunday. No work. Discharged José Navarete, Gregorio Aguirre, Javier Fernandez, and José Antonio Garcia, *macheteros*, at their own request.

February 8.—Extended line 11,090 feet. Rapids more frequent, and mountains alternately on either side.

February 9.—Extended line 8,000 feet, *i. e.*, to above Campana, where Lieutenant Very was swept away by the rapids and lost his transit-book. Mr. Menocal arrived with mail. Dr. Bransford left the party. Rainy during night and morning. Have reached a point where by building a dam across the Chagres the level required as a head for the *feeder* can readily be obtained.

February 10.—Lieutenant Leutzé and Mr. Menocal went on reconnaissance and selected location for a dam. Lieutenant Very, in going to run over yesterday's work, capsized canoe and lost two *machetas*. Masters Coffin and Green gauged river and found 1,022 cubic feet per second.

February 11.—Five men engaged as *macheteros* arrived at 4.30 a. m. Located cross-section for dam. Lieutenant Leutzé and Civil Engineer Menocal went on reconnaisance to locate starting-point for aqueduct. In trying to avoid a high hill they struck the river about one mile above Campana. After several unsuccessful attempts to find a low pass, had to give up and get down to the river, which was both hard and dangerous, as the hills were almost perpendicular.

February 12.—Procured a guide at Campana; Lieutenant Leutzé and Mr. Menocal then went to lowest pass in the hills and cut a picket down to the river. The party in charge of Lieutenant Very extended survey of river 4,803 feet, to a point selected as the starting-point of the feeder, which is to be run back to the main line, following a grade as nearly as possible, allowing one foot to the mile of fall. Ran 891 feet and cut offset of 3,500 feet, coming out just below Camp Washington.

February 13.—Extended the line 4,000 feet and cut offset of 2,000. Country hilly and rocky and of no value. Received provisions. Mr. Menocal left the party. All hands suffering much from *garrapatas*, or wood-ticks.

February 14.—Sunday. No work.

February 15.—Ran 6,066 feet with transit; level behind. Country hilly. Cut offset to river (N. W. 3,500 feet). No low land between line and river. Crossed a savanna, which one of the rodmen foolishly set on fire, giving the party some trouble to escape.

February 16.—Shifted camp down the river. Mr. Green called it Camp Sunnyside.

Camp Sunnyside, Chagres River, February 17, 1875.—Lieutenant Very and Mr. Green cutting an offset 5,000 feet perpendicular to river; Lieutenant Leutzé, with Mr. Coffin running up the level. Cammander Lull came to Camp. Received provisions. Discharged Eloi Henriquez. Sent Master Green to the doctor with Henry Williams, as the latter had cut his arm badly and we were unable to check the bleeding.

February 18.—Commander Lull, accompanied by Lieutenant Leutzé, went up the river to inspect starting-point of aqueduct line, location of dam, &c. Lieutenant Very went on reconnaissance, and found generally hilly and rocky country. Master Green and Henry Williams returned. Discharged José Vera, Ange Maria, Jim Tomas, *macheteros*, and shipped Eusebio Vasquez, José Pablo Quesada, Miguel Gomez, Pascal Narvaiz in their places.

February 19.—Turned to the right 65° and extended line 5,000 feet. At about 4,000 feet struck low land of proper elevation. Came to camp by picket which was cut February 17.

February 20.—Commander Lull left the party. Charles Arbeaud went on two days' leave. Lieutenant Leutzé sick. Line was extended 3,096 feet. As elevation was too low at that point, Lieutenant Very went ahead and found that line had to be changed.

February 21.—Sunday. No work.

February 22.—Lieutenant Leutzé sick. Extended line 5,032 feet, running over an elevated plain.

February 23.—Ran 3,000 feet. Ground fell suddenly, and changed to a large wide plain. The line ran along a small tributary of the Rio Chilibri until it crossed the latter. A reconnaissance on grade-line up the valley showed it would be useless to deviate line. The Chilibri had to be crossed by swimming; this delayed the work some time. The transit became wet, and work had to be suspended. Cut a picket along the Chilibri to the mouth. Found broken country. Charles Arbeaud returned from Aspinwall.

February 24.—Established Camp Hunter, just below the mouth of the Chilibri. Slight showers during the afternoon.

Camp Hunter, Chagres River, February 25, 1875.—Went up the Chilibri in canoes. Found it a dirty river; average depth about 7 feet; very little current. The line was extended 5,000 feet, leaving the valley of the Chilibri at a small house situated on an elevation. Lieutenant Very climbed up the same, and could plainly follow the two ranges inclosing the valley of the Chilibri. Shaped course to run between the mountains of Juanmima and San Salvador. Cut trail to river. Fine weather.

February 26.—Ran 5,000 feet over mountains and along the quebrada of Juanmina, which runs between the peak of that name and the one called San Salvador. Returned to camp by a road leading to the Hacienda of Juanmina. Master Coffin and Henry Williams went down the river to the camp of party No. 2, to be treated by the surgeon. Received mail and provisions.

February 27.—Several of the men being sick, the line could only be extended 4,300 feet. Character of country the same. From the second elevation crossed, the church of Cruces could be seen, and also that it would be necessary to turn to the river to strike lower land. It was very evident that there was no "mean" elevation; only high or else very low land. Stopped work at the quebrada of Fulupa, and cut trail to intersect road from Cruces to Pibá. Master Coffin and Passed Assistant Surgeon Bransford visited the camp.

February 28.—Sunday. Lieutenant Colby visited camp. Lieutenant Leutzé went down the river to Obispo, to consult with Mr. Menocal in regard to the line.

March 1.—Lieutenant Leutzé joined the party at Pibá, on their way to work. Made 4,000 feet, running across spurs and quebradas. Made reconnaissance to below Cruces, striking the old transit road from that place to Panama. Master Green and party and Mancel Philp were lost in the woods, but returned late in the evening. Commander Lull came to camp. Shipped Candelario Segundo.

March 2.—Commander Lull and Lieutenant Leutzé made a reconnaissance up the Chilibri. Found low banks on both sides, excepting in one instance on the left bank. Sent for instruments, &c., as Commander Lull proposed to establish the fact that the Chilibri could not be crossed at a more favorable place by an instrumental examination.

March 3.—Started work at distance-stake 281 and ran line on grade as nearly as possible. Made several reconnaissances, but none with any success. Made 1,600 feet. Received provisions.

March 4.—Continued line 2,000 feet and then abandoned it, as its object was attained. Commander Lull left the party. Lieutenant Very went to party 2 to get new level-tube for transit.

March 5.—Could not work, as transit was out of repair. Lieutenant Very, Master Coffin, and Henry Williams returned. Discharged Candelario Segundo.

March 6.—Started a grade-line at distance-stake 334, in order to go around the mountain of Juanmina, but found it impossible to keep on grade, as the sides of the mountain were too steep to set up the instruments. Much time was lost in reconnaissance, and only 2,800 feet run.

March 7.—Sunday. No work. Fine weather.

March 8.—After a careful reconnaissance, concluded to run along the edge of the mountain of Juanmina until the main line would be intersected. Shaped course accordingly, and ran 5,200 feet over spurs and gullies.

March 9.—After running 512 feet, intersected the old line. Carried instruments to the end of same, and then cut offset of 2,600 feet to the river. Master Green returned. Received mail.

March 10.—Shifted camp to Camp Ammen. Master Coffin on the line running up the level. Weather rainy early in the morning.

Camp Ammen, Chagres River, March 11.—Lieutenants Leutzé and Very went to Aspinwall. The latter returned, but former remained on sick-list at Bojio station with party No. 2. Master Green on line running up the level. Acting Assistant Surgeon T. Chiola, U. S. N., arrived from the United States and reported for duty in the party by order of the commanding officer.

March 12.—Ran 5,443 feet over level country. Intersected transit road from Panama to Cruces about 400 feet from end of day's work.

March 13.—Extended the survey 5,775 feet; first part broken country, the last part level.

March 14.—Sunday. No work.

March 15.—After running 2,310 feet, the main line of party No. 2 was intersected at the point already chosen, and the feeder-line therefore completed. Country very broken. Lieutenant Leutzé returned. Gauged the Chagres River at same place as January 23; found 647 cubic feet per second. Civil Engineer Menocal and Dr. Bransford visited the camp.

Camp Ammen, March 16.—By direction of Commander Lull, commenced survey on main canal line, extending from the site of proposed viaduct toward Aspinwall, following a general compass-course, but could not start work until 8 a. m. on account of heavy fog. Ran 2,500 feet, and stopped work at 1 p. m., in order to go on reconnaissance, which was done by Lieutenants Leutzé and Very. Sent two small canoes to Gatun and hired another from Francisco Larosa. Received provisions. Sent Henry Williams to Aspinwall.

March 17.—The line was continued 1,500 feet, following the right bank of the Chagres. Work very difficult, on the slope of a very steep and slippery hill, broken by deep gullies. Cut offset to river, and returned to camp along the banks, as the picket was too difficult to walk over. Dr. Chiola went to party No. 2. Henry Williams returned.

March 18.—The party extended the line 1,300 feet, between the Cerro Pilado and a smaller hill, over a mass of fallen trees. This and no shade made the work so hard, that it had to be suspended about 11 a. m. Lieutenant Leutzé went on reconnaissance, ascended a high cleared hill, and saw all the country ahead. There being no choice, concluded to run the line on the course marked on the map. Followed a path which led to Gorgona, and from there walked along the railroad to Matachin. Lieutenant Very went to Aspinwall. Dr. Chiola came to camp for medicine.

March 19.—Shifted camp to near Gorgona, and named it Colby. Lieutenant Very returned. Received mail.

Camp Colby. March 20.—During the night, our dog was taken by an alligator and two chickens by a wild-cat. The line was run 3,100 feet over very broken country. Dr. Chiola returned.

March 21.—Sunday. No work.

March 22.—Ran 5,100 feet. Country very broken and rough. Mr. Menocal joined the party.

March 23.—Extended line 5,027 feet, of which first part was level, but latter very rough.

March 24.—Shifted camp to Mamei. Lieutenant Very named it Camp Jeffers. Lieutenant Leutzé and Dr. Chiola went to Aspinwall; also Mr. Menocal. The two former returned, but the latter remained with party No. 2.

Camp Jeffers, March 25.—No work on line, in order to allow the level to catch up. Mr. Menocal came to camp; also Mr. J. B. Philp, draughtsman. Rainy during the evening.

March 26.—Extended line 3,500 feet over partially level and partially broken country. Mr. Gerald McKenny, of the New York Herald, joined the party.

March 27.—Could not determine exact distance made, as the party was caught in a bush-fire and had to run for their lives. The chain had measured 3,200 feet. Discharged Henry Williams.

March 28.—Sunday. Lieutenant Leutzé and Mr. Menocal went on reconnaissance to San Pablo.

March 29.—Chained 1,200 feet of Saturday's picket and extended line 5,000 feet. Shifted camp to San Pablo station by canoes. Took up our quarters in the track-master's cottage.

Camp San Pablo, March 30.—Ran 5,200 feet over mostly level country. Commander Lull visited the party.

March 31.—The line was continued 3,200 feet over level country. Cutting very hard.

April 1.—After running 4,600 feet over level country, at 11.20 a. m. connected with line of party No. 2 at distance 9 + 25 from offset, opposite mile-post 21 of the Panama Railroad, thereby finishing the line.

April 2.—Sent two canoes to Gatun. Mr. Menocal and Dr. Chiola left the party and went to Aspinwall. Lieutenant Very also left party and took some of the instruments and stores down. Masters Coffin and Green finished leveling and then went to Aspinwall. Discharged Charles Arbeaud. Paid the laborers.

Aspinwall, United States of Colombia, April 3.—Discharged all the laborers (*machateros*); also Joseph Ambrosio. Lieutenant Leutzé took remainder of party and stores to Aspinwall, and reported to Commander Lull.

Very respectfully,

E. H. C. LEUTZÉ,
Lieutenant, U. S. Navy, in charge of Party No. 1.

Commander E. P. LULL, U. S. N.,
Commanding Expedition.

JOURNAL OF PARTY No. 2.

LIEUT. H. G. O. COLBY, U. S. N., IN CHARGE.

Aspinwall, United States of Colombia, January 19, 1875.—The party was organized as follows, viz:

Officers.—Lieut. H. G. O. Colby, U. S. N., in charge; Lieut. E. D. Taussig, U. S. N., transit; Master H. L. Green, U. S. N., level; Lieut. J. F. Moser, U. S. N., joined the party January 25, and was put in charge of the level; Master Green transferred to party No. 1 January 27; Mr. J. E. Buck, commander's clerk; J. Westerfield, chainman; R. L. Burnett, rodman.

Wednesday, January 20.—Both parties left Aspinwall, under command of Lieutenant Leutzé, by the 7 a. m. train. At 9.30 a. m. reached Matachin, where we had something to eat, and made preparations for the night. Commander Lull arrived from Panama by afternoon train, bringing with him 18 *macheteros*. Quartered the men at the railroad station-house at Obispo for the night, under charge of Lieutenant Taussig, assisted by Masters Coffin and Green.

Thursday, January 21.—Went to breakfast at 5.30 a. m., after which Lieutenant Leutzé started up the Chagres River with the working-party to clear away for the camp. Pitched camp on the left bank of the Chagres River, one mile and a half from Matachin and opposite Hacienda Santa Cruz. Commenced clearing away at 7.30 a. m.; finished and had dinner at 4.30 p. m. Unanimously voted that the camp be called "Camp Daniel Ammen." Commander Lull left for Aspinwall in the evening.

Camp Ammen, Chagres River, Friday, January 22.—The day was passed in settling down, adjusting instruments, and getting ready for work; also in building cooking-houses. Commander Lull visited camp. Party No. 2 ready for work.

Saturday, January 23.—Left camp at 10 a. m. with party. Made bench-mark on right bank of the Chagres River 100 feet from water's edge, 250 feet south 11° west of house Hacienda Santa Cruz. Ran a line from this point to the railroad-track at Matachin, triangulating the river from Matachin one mile down. The transit instrument was in charge of Lieutenant Taussig, Masters Coffin and Green running the levels.

Sunday, January 24.—Lieutenant Colby and Civil Engineer Menocal went up the river in search of provisions, but were not successful, obtaining only two chickens and one duck. On the way down, the canoeman ran us into a snag, and without a moment's warning we were thrown into the water, the canoe turning bottom up. This being our first experience of the season in the rapids, we considered ourselves fortunate in only losing a canoe-seat and drowning one chicken. Found the rapids in many places deep and swift. The nights are very chilly indeed.

Monday, January 25.—Called all hands at 4.30 a. m. Set off at 5.30 a. m. Commenced running cross-sections for the location of the viaduct over the Chagres River at Santa Cruz. Started from station established January 23 opposite Camp Daniel Ammen at Santa Cruz, and ran about 700 feet to the north; then ran another line nearly parallel to the first; triangulated across the river; ran 1,300 feet south 44° east. At 3.45 p. m. stopped work. Level made station 300 feet south of river.

Tuesday, January 26.—Left camp at 5.45 a. m. Resumed work on the line at last point reached yesterday, carrying it farther, with the same bearing, south 44° 40′ east, to 3,100 feet from Chagres River. The level was carried to a distance of 1,500 feet from left bank of the river. At 1,757 feet from the river an offset was run from the right of the line south 44° 20′ west, intersecting the river Obispo at 205 feet, and the railroad-track 427 feet from the line, and at the end of the sharp curve of the railroad opposite the lower Obispo station. Light shower between 3 and 4 p. m. Lieut. Jeff. F. Moser, U. S. N., arrived in camp and relieved Master Green of the charge of the level. Master

Green was transferred to party No. 1. Dined in camp at 4 p. m. Commander Lull with party. All well.

Wednesday, January 27.—Left camp at 5.30 a. m., and started work at 6.15 a. m. Resumed the line where left off yesterday. Ran on same course 4,610 feet; then 419 feet south 29° 40′ east; then 613 feet south 19° east; resumed course south 29° 40′ east. Total distance, 5,300 feet.

Thursday, January 28.—Commenced work at 6.30 a. m. Resumed the line where left off yesterday. Continued course south 29° 40′ east to total distance 7,662 feet. Passed most of the day with Mr. Menocal on a reconnaissance.

Friday, January 29.—Struck tents at daylight and made preparations for shifting camp. Left Camp Daniel Ammen at 7 a. m. Went to Matachin by water, and there took the cars for Empire station. Arrived at 10 a. m. Built cook-house, and were comfortably settled by night. Mr. White, the superintendent of the Panama Railroad, has kindly placed the house at this station at our disposal. The trains stop whenever a signal is made. Not having a clock, purchased a cock-chicken, and it is to be hoped that he will "wake" us in the morning.

Empire Station, Panama Railroad, Saturday, January 30.—Resumed work at point left off on Thursday. Continued on same line to total distance of 9,060 feet to middle of the Obispo River. Then returned to 7,975 feet of same line to avoid a hill and the river. Deflected 27° 30′ to the left, ending at 8,522 feet. Found magnetic deviation 1° 30′ on top of hill (local deviation of the needle). "The chicken" is a great success, as he crows at very early daylight.

Sunday, January 31.—Clear and pleasant. Remained in camp writing letters.

Monday, February 1.—Resumed work at point left off on Saturday. Continued on line to 8,923 feet, where deflected 28° 04′ to the left, and ran course south 23° 5′ east to 11,513 feet. Passed most of the day on a reconnaissance. All boys should learn to climb trees when they are young, as they may find the knowledge useful to them at a later period of life. The line passed close to a very pretty hacienda. The old lady was very kind, and invited us in to have some fruit. Her small child "had the air" of having recently been ill with small-pox, and the discovery of the child caused the party to move on quickly, alleging as an excuse for so doing pressing engagements. Commander Lull and Mr. Menocal with the party on the line.

Tuesday, February 2.—A grand *fiesta* in all the villages to-day. Our natives have refused to work, giving as a reason that "it is wicked, and snakes will bite them." Tried to obtain horses to make a reconnaissance, but they would not be caught. Went to Aspinwall for supplies, and was very glad to return to camp.

Wednesday, February 3.—Commenced work at station 9, point left off on Monday. Ran an offset south 27° west to the railroad. Distance to center of the Obispo, 93 feet. Total distance to railroad, 328 feet. Returned to station 9, deflected 32° 10′ to the left, and continued line south 55° 15′ east. Crossed the Obispo at ten-feet falls, and again crossed Obispo 340 feet from falls. Continued line to station 10. Total distance, 12,640 feet. Deflected 17° to the right line south 38° 15′ east. Continued to 13,280 feet. Made a reconnaissance with Mr. Menocal. On our return, found Commander Lull in camp, having brought with him, as usual, all the good things necessary for life. Think the natives must have seen snakes, from the noise they made coming home last night, and their sickly appearance this morning.

Thursday, February 4.—Continued from point where left off yesterday on the line south 38° 15′ east to 16,376 feet. Discharged three *macheteros*, they being more fond of rum than of work.

Friday, February 5.—Resumed work at an early hour. Continued to station 11, 1,705 feet; deflected 35° to the right, and continued to 18,453 feet, running through thick jungle and palms. Lieutenant Taussig was taken very ill on the line, and was at once removed to camp, Lieutenant Moser taking the transit and continuing the line. Commander Lull passed the night in camp. Went up the river in search of Dr. Bransford. At sundown I reached the place where party No. 1 had been in camp. From a native I learned that Mr. Leutzé had shifted camp that morning higher up the river. Returned immediately, that I might shoot the rapids before dark. At Obispo station I met the "boss" of the Empire station coming on horseback with a note for me, informing me that Mr. Taussig was better. After reading the note, I mounted the horse, the "boss" getting up behind; and such a ride as we had through the bush and gullies! On our arrival at Empire, found a good supper awaiting us, and we, of course, were happy.

Saturday, February 6.—Resumed line. Deflected 53° to the left at station 12, 19,360 feet. Course south 57° 20′ east, and local attraction very evident at this point. Crossed the Obispo three times between 21,486 feet and 22,240 feet. Continued line to station 13. Total distance, 22,677 feet. Made the longest run of the season, 4,000 feet. Cutting during the morning was very easy, but during the middle of the day made very little progress; toward the afternoon, however, it was again better, and we continued on our "wild career," the leading *macheteros* cheering us with an occasional song or shout. Passed camp at 1.30 p. m. Braced up the invalid with a call and filled the canteens with lemonade. *Garrapatas*, or wood-ticks, very troublesome. Mr. Menocal picked off his person not less than thirty in one half hour. Mr. Moser found two iniguas in his right foot. Burnett, the rodman, being at leisure, volunteered as axeman. He did well until late in the afternoon, when he made a mistake of a lifetime, by cutting down a tree which contained a wasp's nest. He remarked afterward that his "left ear felt as large as his head." We find the farm stock of the neighborhood very social—goats, cows, pigs, and horses walking into the camp without being invited. A large pig is now just making rapid exit from the gate with something attached to his tail, and, judging by appearances, he must have made the acquaintance of the cook.

Sunday, February 7.—A bright pleasant day. Made a reconnaissance as far as Paraiso station.

Monday, February 8.—Lieutenant Taussig returned to duty and took charge of the transit. Mr. Menocal left this morning to visit the other camp up the Chagres. Commenced work at station 13. Deflected 18° to the right and continued to 25,945 feet.

Tuesday, February 9.—Continued to 26,629 feet. Deflected to the left 40°, to avoid crossing railroad. Ran offset to railroad 92 feet. Ran course south 79° 10′ east to 27,626 feet. Commander Lull visited the line; then returned to camp with us and passed the night. Westerfield, chainman, was taken ill on the line this morning and sent to camp. Three *macheteros* down with fever.

Wednesday, February 10.—No work to-day, for, being Ash Wednesday, the natives declined to work. Made a reconnaissance with Commander Lull and Lieutenant Taussig. Dr. Ricker came out from Panama by the morning train. He pronounced Westerfield out of danger. Dr. Bransford, U. S. N., arrived in 10 a. m. train from Aspinwall. Was very glad to see him for many reasons, and hope that he will reduce the "sick-list," which is unusually large. All hands well in party No. 1 at Camp Washington.

Thursday, February 11.—Commander Lull was in camp and on the line to-day, and passed the night with us. James Boyd (cook) was taken suddenly ill this afternoon with a "congestive chill." Sent a man to Panama for medicines. Commenced work where we left off on the 9th, Tuesday. Continued to 28,618 feet. Deflection 40° to the right to resume former course. Continued to 29,909 feet.

Friday, February 12.—Crossed the "summit" this afternoon at 30,849 feet. Ran offset to railroad, distance 283 feet; offset to left of line 137 feet. Continued line to station 16, 31,679 feet. Ran offset to railroad 475 feet at station 16, making an angle of 84° 05′ with the line. Passed through a corn-field; a small house on the left of the line. James Boyd (cook) died at 3.30 p. m. He had lived on the Isthmus for many years, and had exhausted his vital forces by dissipation.

Saturday, February 13.—At 8 a. m. a coffin was received from Panama. Made preparations for the funeral. At 10.30 a. m. James Boyd (cook) was buried with the customary ceremonies. Continued work in the afternoon. At station 16, deflected 4° to the left; continued to 32,573 feet. Dr. Bransford captured a small tarantula as he was about to crawl up Lieutenant Moser's back, and this occasioned some excitement. We placed our friend at once in alcohol, and watched its effect upon him. Dr. B. also caught a bat, the station being infested with them. Commander Lull went to Aspinwall.

Sunday, February 14.—Mr. Menocal arrived just as we were going to breakfast. Passed the morning at the river catching fish for specimens. By means of a piece of bacon, Dr. Bransford would entice the fish into a joint of a smoke-pipe, then pull the pipe up quickly and deposit the "small fry" on the land. We caught several with bent pins fastened to a string. Have experienced great trouble with the natives employed as *macheteros* this week, many of them being down with the fever, and the others shirking work whenever an opportunity offered. The cutting has

been mostly through underwood and cane. Passed through several "palm-swamps," dry at this season, but showing by the trees that the water had at times risen to a height of 15 inches.

Monday, February 15.—Moderately easy cutting. Crossed the railroad at 3 p. m., when we stopped work and turned back to camp. Passed the greater part of the day on a reconnaissance. Visited the Rio Grande, and received an idea of its general direction, and took my first draught of its water.

Tuesday, February 16.—Cutting very hard to-day. Crossed the Rio Grande several times. Visited Paraiso, and followed the Rio Grande for a considerable distance. Saw a tiger-cat and several alligators.

Wednesday, February 17.—Having a slight attack of fever, remained in camp. Sent Westerfield to the Rio Grande station to make preparations for shifting camp. Lieutenant Taussig in charge of line. At 7.30 p. m. Master Green arrived from the other camp with the boy Henry, who came to see the doctor, having received a severe cut upon his arm. Line resumed at 37,496 feet in the valley of the Rio Grande. Ran the same day to 39,814 feet (south 61° 10′ east).

Thursday, February 18.—Resumed work as usual, Lieutenant Taussig in charge. Shifted camp by railroad to Rio Grande station; Dr. Bransford, in addition to his own duties, taking charge of everything. We reached Rio Grande at 11 a. m., and when the party returned at 4.30 p. m. all things were in as good order, thanks to Dr. Bransford, as if we had been here a week. He demonstrated the fact that camp can be shifted and line kept going at one and the same time. Regret very much the absence of a good bathing-place; also, that there is no spring-water nearer than two miles. Owing to a swamp which comes close up to the back fence, this must be an unhealthy station. We are near the Rio Grande, but as this point of the river is below tide-water, it is of very little use to us, being so muddy that the water cannot even be used for washing clothes. The drinking-water at this station is caught in large tanks, it running from the roof of the house, and during the rainy season enough is obtained in this way to last through the dry weather. I fear if we remain here long we shall be down with the fever. Master Green and boy Henry left this morning early. The line was prolonged, with same bearing, to 40,000 feet, deflected 4° to the left, and extended to 41,575 feet, where another deflection of 4° to the left was made, and the line carried to 42,298 feet.

Rio Grande Station, Panama Railroad, Friday, February 19.—Lieutenant Taussig came in from the line with the fever. Mr. Menocal relieved him of the transit, Lieutenant Moser taking charge of the line. Line was resumed at point left off yesterday and extended to 44,708 feet, where a deflection of 14° 47′ to the right was made, and carried to 45,843 feet.

Saturday, February 20.—Following the same course, the line was extended to 49,963 feet. Commander Lull walked over the line from the summit and came into camp.

Sunday, February 21.—Still and warm. The extra train from Aspinwall passed in the morning.

Monday, February 22.—Resumed line at point left off and extended it to the edge of a swamp 54,700 feet. Commander Lull visited the party. I went to Panama on duty and remained overnight.

Tuesday, February 23.—An offset was run from the last transit-point on the line to the railroad, and the survey was then followed along the track to clear and meet the swamp again at mile-post 46, a distance of 23,670 feet from the last transit-point on the line.

Wednesday, February 24.—Resumed work at station 25 of previous day, about 400 feet to the left of the railroad, and ran south 55° east nearly parallel to the railroad. The line was extended to the Bay of Panama. Gave the *macheteros* the money they desired and twenty-four hours' liberty, with orders to be at Obispo Friday morning.

Thursday, February 25.—Commander Lull came down in morning train from Aspinwall, and found us all packed and ready to shift camp. Shifted camp by morning train to Obispo station. Saw that everything was in order, and then the officers of party No. 2, accompanied by the commander, took the train for Panama, where we arrived in season for a good dinner at the Grand Central Hotel, and passed the night, sleeping in beds for the first time for many nights.

Friday, February 26.—Turned out at our usual early hour. Visited the line with Commander Lull and Mr. Menocal. Lieutenant Moser was engaged during the morning in the freight-depot of the Panama Railroad Company doing some leveling. Returned to the Obispo station by the after-

noon train, Mr. McKenny, of the New York Herald, being of the party. At 5.30 p. m. Master Coffin arrived from Camp Hunter with boy Henry. Mr. Coffin looks ill and used up. Black beans and bacon as constant food are not conducive to good health or strength. Commander Lull went on to Aspinwall, having a touch of fever.

Obispo Station, Panama Railroad, Saturday, February 27.—Began work by running cross-sections to locate a basin. Work was very successful. Returned to camp at 4 p. m. Mr. McKenny went back to Aspinwall. Mr. Coffin and the doctor visited camp Hunter. Coffin is to remain with us a few days to see what fresh meat and a change of scene will do for him. Regretted to hear that Lieutenant Leutzé was ill.

Sunday, February 28.—Passed the morning mending clothes for next week's work. Visited Camp Hunter, took dinner there, and brought Lieutenant Leutzé down in the evening. Found the Chagres very low, and experienced some difficulty in getting over the rapids.

Monday, March 1.—Lieutenant Leutzé left us at 3 a. m., and started up the river for his camp. Began making preparations to shift camp. At 6 a m. the *macheteros*, hearing we proposed shifting camp and finishing the cross-sections the same day, refused to work unless paid off. Having paid them on Wednesday last the money they wished for, and also given them two days liberty, did not think it necessary to pay so soon again, and therefore discharged them all; then went to Matachin. hired a gang of men for the day, and finished the work at Obispo. By the morning train shifted part of camp to Frijoles, and left the rest, under charge of Master Coffin, to come by evening train. Commander Lull visited us at Frijoles; after which he took the afternoon train for Matachin, intend, ing to visit the other party up the Chagres. Lieutenant Taussig arrived by afternoon train with working-party and rest of camp furniture. Went to Buena Vista and engaged a gang of men to begin work to-morrow.

Frijoles Station, Panama Railroad, Tuesday, March 2.—Began work at an early hour, as usual. Men arrived from Buena Vista at 5.30 a. m. Ran offset from mile-post 21 north 84° 45′ east to 1,200 feet; from there ran line north 5° 15′ west. The cutting is remarkably easy, and the country looks comparatively level.

Wednesday March 3.—Continued work as usual. Cut offset 167 feet south of mile-post 19 to 800 feet. Made several reconnaissances. Sent Jones (chainman) to Aspinwall for shoes. Went to Aspinwall on duty. The line running through level country and dry swamps.

Thursday, March 4.—On my return from Aspinwall found that the men who had been discharged at Obispo had come down to be taken on again, but sent them away at once. Sent Jones to Aspinwall with orders not to return. Paymaster Clarke visited camp. Commander Lull passed in train for Aspinwall. Lieutenant Very remained overnight with us, having come down to obtain a level-tube for his transit.

Friday, March 5.—Went to Buena Vista and vicinity with Commander Lull and Mr. Menocal. Also made a reconnaissance of the hills. On our return, found the head of the line coming by the station-house 100 feet to the rear. Commander Lull and Mr. Menocal passed the night in camp. Heard to-day that Matachin had been entirely destroyed by fire, the flames spreading so rapidly that only the people escaped, leaving everything behind them. Lieutenant Very, Master Coffin, and boy Henry left for Camp Hunter.

Saturday, March 6.—Continued work on line. Visited Buena Vista and vicinity with Commander Lull and Mr. Menocal. The new men work very well, and seem to take great interest. Commander Lull and Mr. Menocal returned to Aspinwall. End of line 250 feet from railroad 300 feet south of mile-post 18.

Sunday, March 7.—Clear and hot at 9.30 a. m. Steam-engine Colon from Aspinwall to Matachin stopped at station, and the engineer and master-machinist took breakfast with us. We found the latter not only a good workman but an uncommonly good talker. We enjoyed his stories very much. When they went back, accompanied them as far as Buena Vista, and from there walked to Bohio station, returning that afternoon. Found the station-house at Bohio empty and in good condition. If possible, will shift camp on Tuesday. Lunched off "Boston baked beans." First Sunday that native working-party has not been more or less under the influence of liquor, and I am inclined to think that we have at last good men.

Monday, March 8.—Visited Aspinwall on duty, to consult Commander Lull. Found Mr. Meno-

cal quite ill. Light showers during the afternoon. Dr. Bransford went to Aspinwall to see Mr. Menocal.

Tuesday, March 9.—Resumed work at an early hour, running through level country. Roused during the night by hearing a fearful noise in the vicinity of the chickens, and made preparations to shoot somebody or something, when a slight rustle was heard, and then all was still.

Wednesday, March 10.—Continued work on line and shifted camp to Bohio station. It rained quite hard during the morning. Commander Lull passed on his way to Panama. This is decidedly the best house we have been in, it being in good repair and having pleasant surroundings. The water at one time, I am told, was very good, but now it is very bad. In front we have a large orchard of mangoes and guavas.

Bohio Station, Panama Railroad, Thursday, March 11.—Commander Lull visited the line this afternoon. Ran 3,500 feet. On return to camp, found Lieutenant Leutzé and Mr. Menocal. Both are under the care of the doctor.

Friday, March 12.—Running over high hills and through valleys. The cutting is remarkably easy. The country through which we are passing to-day has not been cleared for years, if ever. The trees are fine and large, and many of them look as if they would make good timber. The hills are very steep, and one is almost perpendicular. Ran 3,600 feet. Commander Lull returned to camp at 6.30 p. m., having been engaged for four hours in building a road.

Saturday, March 13.—Cutting very easy. Ran 4,500 feet. Passed some magnificent trees. The paymaster visited camp with money. After dinner, paid the men. Mr. Menocal went on the line for a short time in afternoon. Commander Lull went to Aspinwall. A tiger-cat crossed the line.

Sunday, March 14.—Clear and pleasant. Discharged four of the men, but was able to fill their places by evening. Lieutenant Leutzé and Mr. Menocal, with myself, took a long walk down the track. Saw the Chagres and examined the ground where it is proposed to run the line.

Monday, March 15.—Began work as usual. Visited Lion Hill with the track-master of this section of the railroad, and made arrangements for shifting camp to-morrow. Reached the line about 8.30 a. m. A very poisonous snake was killed by one of the party. The line ran over the western edge of a range of hills. I am convinced there is a valley situated 300 feet to the left, and intend running offsets to-morrow, which will show the contour of the hills. Ran 3,300 feet. Deflected the line, while running through the hills, to the left. Commander Lull and Paymaster Clarke passed, on their way to Panama, and were joined at Bohio by Mr. Menocal and Dr. Bransford. This party propose to reconnoiter the Chepo River. One native sick to-day, and he is the first man down since leaving Rio Grande.

Tuesday, March 16.—Carried on work as usual. Shifted camp by morning train to Lion Hill station. Found the house very dirty and hardly fit to live in. The water is very poor, and there is very little of it. Ran several offsets south of mile-post 13, to show contour of the hills. Mr. Buck, captain's clerk, came in from the line ill with the fever. Sent to party No. 1 for the doctor.

Lion Hill Station, Panama Railroad, Wednesday, March 17.—Carried on work as usual. Ran line to edge of swamp. Made a deflection of 90° to the left, and ran the line to the railroad, continuing along railroad until the line reached a point where it was possible to connect by running in and running back. Stopped work at 3.45 p. m. On return to camp, found Drs. Chiola and Badger. During the morning the line ran through a banana plantation, and I was obliged to cut down a few trees. I had hardly done so when the owner of the plantation, "Francisco," came after me with a large bill for damages. I went back with him to estimate the value of the trees claimed to have been injured, and found that this man had claimed damages not only for every tree that had been blown down or injured in any way within the past month, but even for those that had died or were decaying. He was at last convinced that $8 was all that would be allowed him. Eight trees only were injured, and but three of these were of any size, two out of the eight having merely lost their fronds.

Thursday, March 18.—Continued work as usual. Ran from track the proper distance; then back until line struck the swamp; then returned to the old course and continued on toward Aspinwall. Was obliged to deflect to the left to clear Lion Hill. At 9 a. m. the man Francisco appeared with another man, who presented a writ from the alcalde, which ordered me to put in an appearance

at Buena Vista to answer to the charge of "cutting down banana trees." I was obliged to leave the line, go to Aspinwall for money, and thence to Buena Vista, where the case was settled by the payment of the $8 which had been awarded in the first place as compensation for the loss sustained, the man who served the writ receiving a very severe reprimand from the alcalde for doing so. This man Francisco is the first disagreeable land-owner I have met with on the Isthmus.

Friday, March 19.—Struck Young's swamp; deflected to the left and ran for two thousand feet; then ran over Tiger Hill. I fear the line went a little too high to-day. It can be carried much lower by following the track, or even going 100 feet to the right. Highest elevation of line, 150 feet above railroad. Stopped work at 2 p. m., having run 7,441 feet; the big run of the season. Two of the men down with fever.

Saturday, March 20.—Went on with work as usual. Shifted camp to Gatun. This is evidently the best house we have been in; everything is clean and in good order. Dr. Chiola returned to party No. 1. Coming down on the train, one of the brakemen fell between the cars, and the whole train passed over him. He, however, received only a few slight injuries on the head and back.

Gatun, Sunday, March 21.—A bright, beautiful day. Had breakfast at 8.30, after which Señor Carrera, a neighboring *haciendero*, came with his horses and took me over his farm. From one of the hills I saw the shipping and houses at Aspinwall; also Tiger Hill in the distance.

Monday, March 22.—Continued work as usual. The line is now running through a country consisting mostly of swamps. Commander Lull and party passed on their way to Aspinwall, having returned safely from the Chepo River.

Tuesday, March 23.—Visited Aspinwall in the afternoon on horseback. Found Commander Lull ill in bed.

Wednesday, March 24.—Line passed to-day directly in rear of station-house. Mr. Menocal stopped in camp for a few hours.

Thursday, March 25.—Got the angle where the line crosses the railroad-track, 3½ miles from Aspinwall. Reconnoitered ahead; so far as I went found nothing but swampy land, at this season of the year dry, although in many places the ground is so soft that, in order to set up the transit, it would be necessary to build a foundation. Walked to Aspinwall and saw Commander Lull, who is still suffering and only just able to get about.

Friday, March 26.—The working-party under Lieutenant Taussig went to Tiger Hill to improve the line run there last week. Shifted camp to Empire station; having returned here to improve the line, in running which a deflection was made that we now find was unnecessary.

Empire Station, Saturday, March 27.—Started work early at station 8, Lieutenant Taussig in charge of line. Went to Leutzé's camp, on the Chagres, at Mamei. First trouble with the Buena Vista men occurred to-day; which, however, was speedily settled, and the men agreed to finish the line.

Sunday, March 28.—Clear, with light showers. Have been trying to convince the married men that the "proper thing" to do is to go home in the next steamer; to accomplish which will require no small amount of exertion, as the work must be finished first.

Monday, March 29.—Worked as usual, making 4,000 feet. Commander Lull came up in the afternoon train. He has convinced the married men of the proper thing. *Macheteros* seem contented and work well.

Tuesday, March 30.—On the line at 2.30 p. m. Made preparations for shifting camp to Gatun. Commander Lull with the party.

Wednesday, March 31.—Shifted camp. Sent boy with the greater part of camp equipage to Gatun under charge of Lieutenant Moser. Remained with working-party at Bohio. Began work at 1 p. m.

Gatun, Thursday, April 1.—Working-party went out under Lieutenant Taussig, with orders, if work be finished, to meet train at Lion Hill. While passenger-train was taking on our luggage a gravel-train from Matachin came around the curve, and for a moment I supposed there would be a collision, but just as the passenger-train got under way the engine of the gravel-train struck the last car and landed it on the cow-catcher, which prevented a more serious accident. Stopped for working-party at Lion Hill and sent them on to Monkey Hill, whence they walked back a mile and a half to where the line crosses the track. Working-party came into camp at a late hour.

Friday, April 2.—The men seem cheerful, and hope to finish the line this evening. Having a four-and-a-half-mile walk before them, they started at an earlier hour than usual. Cutting was very hard during the morning, and the men suffered much for want of water, although canteens had been furnished and a man detailed to keep them full. The line struck the beach about dark, and the stake and nail were driven, and the line finished from ocean to ocean. Mr. Buck left the line sick and went to Aspinwall.

Saturday, April 3.—Struck camp, paid the men off, and packed up for home. Moved on board the Pacific mail-steamship Acapulco.

Respectfully submitted.

H. G. O. COLBY,
Lieutenant, United States Navy, Commanding Party No. 2.

Commander E. P. LULL, U. S. N.,
Commanding United States Panama Surveying Expedition.

REPORT OF PASSED ASSISTANT SURGEON JOHN F. BRANSFORD, U. S. N.

CLIMATE, HEALTH, ETC.

RICHMOND, VA., *December* 31, 1875.

SIR: In obedience to your orders, I have the honor to make the following report:

The country along the Panama Railroad is too well known to require description. Lieutenant Leutzé's party, which I accompanied, left the railroad at Matachin to run a line up the Chagres River. The country back from the river about a mile on either side is broken with hills of volcanic formation, occasionally rising to the dignity of mountains. The valley is alluvial, with trap-rock and occasionally sandstone cropping out in the river-banks.

About twelve miles above Matachin a fossiliferous sandstone appears of beach formation and very soft. The banks become abrupt, and cliffs from 50 to 200 feet high appear on either side alternately, as the current has washed first one and then the other in its serpentine course. Proceeding up the river, this rock becomes less sandy as the deeper strata are shown, until it is composed almost entirely of marine shells, becoming a fossiliferous limestone. Professor Endlich, of the Smithsonian Institution, was kind enough to examine specimens of this rock, and pronounced it to be of the middle Tertiary age. It underlies the volcanic rocks. In some places solid strata of oyster-shells show where the bivalves found rich sustenance in ages long gone. The river traverses about twelve miles in finding its crooked way through this range. Following it up one day, I suddenly left the hills and entered the valley through which the old road from Porto Bello passed to Panama. In this valley is situated the miserable village of San Juan.

During the latter half of January and the month of February the climate on the Upper Chagres was exquisite. Blue skies and mountain scenery, the swift-running stream as clear as crystal, and a delicious breeze conspired to make life in the shade and a grass hammock all that a lotus-eater could desire. The wild animals seemed to have left the hill-country and migrated to the swamps nearer the sea. For, although we heard much of tigers, none were to be seen; and snakes were very scarce. I was in the woods hunting most of the time, and only saw two or three during the month. There were numbers of less formidable "varmints," tarantulas, &c. At one of our camps an ugly-looking caterpillar, covered with rows of sharp spines, got into the breeches-leg of one of the men, and made his movements quite lively for a few moments. As usual, the natives asserted "*el mata,*" "it kills"; but a little ammonia applied and swallowed soon relieved the severe urticaria-like welts caused by its sting.

As elsewhere in tropical America, ants swarm in every direction. I overturned an old log, exposing the nest of a colony of black ants. A moment of confusion, and each pupa was seized by an ant that started off to save it from the general ruin. I caught two or three on my *macheta* and raised them more than a foot from the ground. They dropped that distance, but held fast to

their treasure. The hold of one was broken by the fall; he shook himself, gathered up his burden, and rushed off.

There was an abundance of fish in the river, but the water was too clear and the fish too shy for any but the skill of the natives. They were very successful at night. While one managed the canoe noiselessly another crouched in the bow with a torch in one hand and *macheta* in the other, and as the fish rose to the light a quick stroke secured it. *Zavalos* (fish weighing three or four pounds) swarmed under certain trees, and fed on the leaves as they fell into the water. At these points the natives erected scaffolds, to get a proper elevation, and shot them in large numbers. Alligators were extremely rare. Pigeons, partridges, and curassows were plentiful.

On the 9th of February I left Lieutenant Leutzé's camp, and reached Matachin about 9 p. m. Rosa, our resident charge d'affaires, prepared for me a neat couch in her store, where tired nature's sweet restorer had to contend with the combined aromas of jerked beef, cheese, and codfish. In the wee small house I was awakened by a noise at a window just over my cot. Prepared for a garroter or other desperate character, I quietly waited until the window opened, and a young Spaniard appeared. He was a beau just from the fandango, and, with a profusion of apologies for interrupting me, he crawled in and lit a candle. Taking advantage of the opportunity to survey the situation, I looked around. Mine hostess was sweetly dreaming in a hammock, immediately beneath which, gracefully reclining, lay the fair Carolina, the belle of the village. In the other end of the room two negro men were sleeping. The caballero quietly stretched himself on the counter, with a cake of cheese for a pillow, while a bottle of gin in close proximity to his nose doubtless suggested dreams of perpetual fiestas.

Arrived at Empire Station I found one case of fever in Lieutenant Colby's party; and next day the old Jamaica negro who acted as cook had a congestive chill, which baffled my best efforts and took him off. Dr. Reicker, of Panama, who has had much experience on this Isthmus, told me that the negroes sometimes succumb in the most helpless manner to attacks of no extraordinary severity.

March 15, Mr. Menocal, Paymaster Clarke, and I accompanied Commander Lull in a small schooner to the Rio Chepo, about forty miles south of Panama. The breeze died out late at night, and we flapped along in the laziest style, reaching the mouth of the river at 11 a. m. on the 16th. There was a small village of wretched huts here; the inhabitants have no visible means of support, except the turtles and fish, which latter are harpooned in such wasteful abundance, that they are fed to the hogs. One elegant large fish called the *Mira* is particularly esteemed for the delicacy and flavor of its flesh.

In the evening we started up the river, and again the wind failed us about midnight, leaving us to depend on the tide and a couple of rude oars. Near the sea the banks are very low and are covered by high tide. The lowlands are wooded with beautiful mangrove trees. There was a Spanish colony settled here once, but the deadly fevers of these swamps made such ravages the first year that the settlement had to be abandoned. The air was saturated with the peculiar odor of salt-water swamp; jelly-fish and animalcules of every description being left by every receding tide, while the high tide and muddy banks keep the river foul and make it a paradise for alligators. We saw between thirty and forty on one mud-bank.

There was a notable lack of taste and art in the construction of the canoes seen. Shoveled at each end, of rude shape and workmanship, they were entirely wanting in the grace and symmetry of the pointed and often painted canoes of the Chagres.

About twenty mile from the sea the country began to be hilly, although the tide ran strong as far up as we went. After spending two chilly nights on the miserable boat, toiling against unpropitious winds and tides, we cannot express our delight when we reached Jesus Maria, the estate of Dr. Kratochvil, and our objective point. This gentleman owns what was once a magnificent sugar estate; and although it is still princely in extent and fertility, the cultivation of the sugar-cane has been abandoned, on account of the unreliability of labor. Settled here in the wilderness, with his nearest neighbors in Panama, the doctor lives in patriarchal style. Lounging around under the shelter of his ample roof may be noticed the Danish captain and Portuguese crew of his schooner, Indian hunters, and wood-cutters, domestics, and the aboriginal maiden of the neighboring forest.

We found here, besides every other luxury that could contribute to comfort in this climate, a large and select library of English, German, French, and Spanish works. With such surroundings, hospitality most cordial, genuine Chateau Lafitte and Hennessy to make glad the hearts of weary travelers, our satisfaction, as we swung in our hammocks and chatted, may be imagined.

The doctor had a magnificent orchard of tropical fruit-trees. There were in the greatest profusion cocoa-nuts, oranges, lemons, limes, papayos, marañons, granadillas, pineapples, bananas, &c. But his especial hobby was a garden of lettuce, cabbage, spinach, tomatoes, &c., with roses on the borders. This garden was watered every evening, and succeeded very well. The principal difficulty experienced was in preventing the destruction of the vegetables by insects and nocturnal animals.

On the 18th I went hunting with an old Indian, who took his pants off as soon as he got into the woods, to avoid tearing them. He wore sandals, and seemed not in the least afraid of snakes. In reply to inquiry, he said that he had repeatedly known people to be bitten by poisonous snakes, but all were saved by tying the limb above the bite, bruising a plant called *cordoncilla*, applying it to the wound, and taking some of the juice internally with aguadiente (crude rum). The same plant was shown to me by an old hunter in Nicaragua. It was not in flower either time, so I did not take a specimen. It is a slender plant, about two feet high. After biting a small piece of the stem or leaf, a cool, tingling, and then a numb sensation is left in the mouth.

At one of our meals here a tapir-steak was served up with much seasoning, and proved a savory dish; coarser than beef, and with a game flavor.

The vampires in large numbers destroy the fruit and kill the sheep and horses by repeated drawing of their blood.

A few years since a young man went down to the river, as usual, for a bath; while in the shallow water he was seized by an alligator, and before his companions could assist him he was dragged down. It is said that after that time the large old alligator became a man-eater, and would follow the canoes, until the Indians were afraid to go on the river at night, and organized a band that hunted the alligator until he was killed.

On the 27th of March I went up the Chagres to San Juan. Natalio, the boatman, standing in the stern of the canoe, poled the craft a distance of about thirty miles between 9 a. m. and 9 p. m. The river was very low, and frequently at the rapids Natalio had to get out and push the boat along. We passed a watermelon-patch on the river bank. In it was a small rude cross of sticks, intended to fix the evil-eye upon trespassers; and thus the melons were guarded.

The village of San Juan is the most wretched that I have seen in Central America. The inhabitants are a brutal mixture of negro, Spaniard, and Indian; sullen, ugly beggars, very different from the pure Indians of the country. There were said to be about one hundred and twenty-five people there; and I could not, out of that population, on an occasion of feasting, get the wherewithal to make a supper. There was no bread in the place; only a few plantains and some rice. The next morning I managed to get an old rooster for breakfast.

The 27th was *Sabado de la gloria*, and was celebrated with music and dancing. Just outside of the tent in which I tried to sleep a large drum, a small one, and a dozen cracked and screeching voices did honor to the occasion by making night hideous. Natalio, notwithstanding his hard day's work and a bad cough, was up with the music, putting in the extra touches with an accordion.

The only graceful thing noticed at San Juan was the fondness of the women for flowers as ornaments. There, as elsewhere in Central America, the females deck their hair with flowers. Many an ashy wench had exquisite camellias stuck in her wool.

Returning, we reached Natalio's tent on the night of the 28th. Several men were there hiding from a detachment of soldiers stationed at Matachin. A revolution was on the *tapis* and the officers were conscribing without any great show of regularity. In this region, to save fowls from wild animals, they are kept in their owners' huts at night. Natalio's house had two rooms and an attic. On this occasion it was occupied by his wife and mother, several babies, twenty chickens, four roosters, several turkeys and guinea chickens, two pigeons, five birds, two ducks, and three dogs, besides Natalio, myself, and the four gentlemen who did not want to be soldiers. It struck me that the mansion was a little crowded, so I took an inventory.

As the expedition reached Aspinwall on the 15th of January and left on the 4th of April, we were only in the country during the dry season. It was a remarkably dry one, according to the accounts of the oldest inhabitants. It was warm in the sun during the day, but the nights were cool; two blankets being usually required in camp. About the 20th of January the parties separated at Matachin, Lieutenant Leutzé going up the river and Lieutenant Colby across the divide to Panama. The first lived in camp and used mosquito-bars, the second slept without bars in well-ventilated station-houses along the railroad, using the second story. Within two weeks Lieutenant Colby's party began to have fever. Lieutenant Leutzé's escaped it, except a chronic case of Lieutenant Leutzé himself, which was sequel to a former attack, and of a character entirely different from the acute bilious attacks in Lieutenant C.'s party. I joined the latter about the middle of February, and caused them to begin the use of the mosquito-bars. Except immediately after, there was only one more case, and, strange to say, no case of return of fever; a fact probably in a measure due to the prompt treatment of malaria with quinine, many cases, no doubt, having been staved off in that way. My experience in Nicaragua and Panama convinced me that the mosquito-bar is a great protectiona gainst malaria by straining the air of germs and moisture, in the same way that cotton acts in preventing fermentation of matter protected by it. The bar also protects from draughts and cold. At 6.30 a. m., March 4th, the temperature in my bar was 67½°; outside the bar in the same room it was 64½°. Frequently my bar would be very damp or saturated with moisture, while the bedding within was perfectly dry. A bar 7 feet long, 6 feet high, and 5 feet wide contains 280 feet of air, a very comfortable amount to start with; and as all except the bottom surface is exposed, and the thin muslin allows rapid diffusion of gases through its spaces, increased by the movement of the outside air, which was almost always active, and by the difference in temperature, the air was kept in very good condition, as shown by good rest and absence of headache, &c., except in cases where the low tent encroached on this space.

It is well known that the relaxation in sleep, empty stomach, and exposure to the damp air of early morning predispose to malarial fever. It is a good rule to take coffee before getting out of the mosquito-bar, and have breakfast as soon after as possible. The coffee gives the germs a warm reception, if, as some believe, they are swallowed, and the stimulant effect in arousing the nervous and vascular systems before exposure to the damp morning air, whether it is saturated with a poison or organisms that make their entrance through the lungs or stomach, prepares the system to resist the evil influence more effectually.

On the Atlantic side the greater freshness and coolness of the trade-wind coming in strong from the sea increases the salubrity of this country in the dry season.

The greater rainfall and larger number of water-courses contribute to equableness of temperature, while the swamps are densely wooded and thus protected.

On the Pacific slope the tides are very high, leaving on the swamps over which they rise animal matter to add to the deadly vegetable effluvia. This side is warmer, and the slighter rainfall and wind tend to allow the accumulation of poison in low situations.

The only fevers of any consequence experienced by us were near the divide and on the Pacific slope.

At Empire station, on the Atlantic slope, about two miles from the summit of the divide, we had several cases of fever. This station is on flat land near the little river Obispo. The drinking-water here was bad, and the weather warmer than in the Chagres Valley.

From Empire we moved to Rio Grande, a station about four miles from Panama. Situated on the edge of a mangrove swamp which borders the Rio Grande River, it is the headquaters of the famous "Panama" fever. During the latter half of February the wind was from the mountains to the north, but late at night it veered around to the westward and brought up a heavy fog from the swamps.

This is considered the most unhealthy place on the line of the survey, and our experience confirms the belief. Dr. Reicker, of Panama, says that the fevers here in the dry season are rarer but more severe, sometimes approaching the character of yellow fever; whereas in the wet season intermittents are common but comparatively mild; a fact due probably to the greater concentration of miasma in the dry season.

At Empire and Rio Grande we had four obstinate cases, three of remittent type and one per-

nicious intermittent of the Algid variety. The latter (the cook, a negro) died. One of the others took 95 grains of quinine before cinchonism was produced and the fever broken. I hurried these patients away to Panama as soon as possible for hygienic reasons.

The city of Panama is built on rock, high enough to be quite dry. It has the strong currents of the Pacific washing more than two sides, and is protected from the malaria of the Rio Grande by the mountain Ancon, rising just back of the city. It is said to be very healthy for a tropical town. With ordinary police and sanitary provisions there is no reason why it should not be so. It is true a considerable expanse of beach is exposed to the sun at low water, but it is almost entirely rock, and pools remain in which animals that are left by the tide may live until it returns. Then, too, the strong currents that sweep the foot of the ramparts back and forth with every tide wash away all that is left by the buzzards, the self-appointed scavengers of Panama. The foreigners resident here have a healthy appearance, and seem to enjoy life as much as most folk.

Aspinwall has the benefit of the strong trade-wind during the dry season. But in the summer and autumn there is an uncertain breeze from the swamps of the Chagres, and the weather is hot and sultry between showers. It is situated on coral formation, and there are marshes on the land side which come right up to the town. There is a salt-water pond in the heart of the place, which would be no great disadvantage but that it serves as a receptacle for filth. This accumulates here, as there is very slight rise and fall of the tide, and the current through the one or two culverts connecting the pond with the sea is sufficient to change only a portion of the water. The place is miserably dirty, and the inhabitants have no right to expect health.

The stations of Gatun, San Pablo, and Matachin are well situated, and seemed healthy. The valley of the Upper Chagres, a well-drained and hilly country, and during the dry season at least is very salubrious.

Very respectfully,

JOHN F. BRANSFORD,
Passed Assistant Surgeon, U. S. Navy.

Commander EDWARD P. LULL, U. S. N.,
Commanding Expedition.

ON THE BATRACHIA AND REPTILIA COLLECTED BY DR. JOHN F. BRANSFORD, U. S. N., DURING THE PANAMA CANAL SURVEY OF 1875.

By Professor E. D COPE.

BATRACHIA.

1. CŒCILA OCHROCEPHALA, Cope, Proceed. Academy Philada. 1866, 132.
   From the Atlantic side of the Isthmus.
2. MICROPHRYNE PUSTULOSA, Cope, Proceed. Academy Philada. 1864, 180.
   Bohio Soldado.
3. BUFO HÆMATITICUS, Cope loc. cit. 1863, p. 157.
   Camp Santa Margarita.
4. BUFO PLEUROPTERUS, Schmidt, Denkschriften Wiener Academie, 18.
   Bohio Soldado and Camp Santa Margarita.
5. BUFO AGUA, Daudin.
6. HYLA ELÆOCHROA, Cope, Journal Philada. Academy, 1875, supra, p. 105.
   ? From the Pacific side.
7. PHYLLOBATES RIDENS, Cope, loc. cit. 1866, p. 131.
8. LITHODYTES DIASTEMA, Cope, sp. nov.

Approximating *Phyllobates* in the slight development of the vomerine teeth, and further characterized by the shortness of its feet. The former are in two very short transverse patches behind

and within the line of the middle of the choanæ, and separated by an interspace as wide as the length of each. The tongue is obpyriform, rounded and extensively free behind. The *ostia pharyngea* are minute. The *membranum tympani* is indistinct, with a diameter of less than half that of the eyeslit. The head is an oval in outline, with narrowly truncate and depressed muzzle. The canthus is obtuse, but not concave. Nares subterminal; diameter of orbit about equal length of head in front of it. Cranium above slightly convex in both directions.

The toes are short, and the digital dilations are large on all the feet. On the anterior the first toe is shorter than the second. On the posterior the fifth is longer than the third, and reaches the base of the penultimate phalange of the third. The muzzle marks the wrist and the middle of the tibia of the extended limbs.

Color above dark brown; a darker brown between the eyes, which is paler bordered anteriorly. Below, pale brown.

	M.
Total length	.0200
Length to axilla	.0090
Length to tympanum	.0060
Width of head at tympanum	.0070
Length of fore limb	.0115
Length of fore foot	.0035
Length of hind limb	.0270
Length of hind foot	.0120
Length of tibia	.0085
Length of tarsus	.0060

This species resembles the *Lithodytes habenatus*, Cope (supra, p. 109) in the position of the vomerine teeth, but differs much in the form of the feet. In that frog the dilatations are much smaller and the feet much longer. In the hind foot this is chiefly due to the elongation of the fourth toe, which exceeds the third and fifth by three and a sixth phalanges.

The *Lithodytes diastema* was found by Dr. Bransford at the camp Margarita, Panama.

LACERTILIA.

9. Corythophanes cristatus, Merrem.

Bohio Soldado.

10. Basiliscus guttulatus, Cope, sp. nov.

Represented by a young male, which displays a number of remarkable characters. The back and median line of the tail support the membranous crest stretched between the elongate neural spines as seen in *B. plumifrons*, *B. mitratus*, &c., but the head-crest, instead of being covered, as in those species, with large thin scales, presents only small smooth scales like those of the occipital region. This crest is also of smaller size than the species named, only beginning to rise from a line connecting the tympanic drums, although preceded by a keel to near the line of the border of the orbits. It is not much elevated, but is prolonged chiefly backwards, and has a truncate posterior outline. Points in which the species differs from the *B. cristatus* are, the presence of two large scuta bounding the rostral shield above, and the presence of two large labials behind the point of junction with the suborbital ring of scales. There are only ten rays to the dorsal fin, and fifteen to the caudal, the latter graduating imperceptibly to the usual keel. Neither crest is bordered at the margin with large scales. The ventral scales are entirely smooth, while the dorsals are smaller and keeled; the lateral are smaller still.

Color olivaceous-brown above, shaded with leaden on the sides; yellowish below. A few black spots at the base of the dorsal crest. Sides and throat with small black spots. A black band from eye to tympanum, bordered with yellow below. Hind legs and feet with brown yellow-bordered cross-bands.

	M
Total length	.455
Length to vent	.125
Length to axilla	.060
Length to tympanum	.030
Length to orbit	.012
Width between orbits	.016
Length of fore limb	.060
Length of hind limb	.130
Length of hind foot	.063

From camp at Bohio Soldado, Panama.

11. Anolis trochilus, Cope, Proceed. Academy Philada., 1871, p. 215.
Bohio Soldado.

12. Anolis petersii, Bocourt, Miss. Scient. Mexique, p. 79.
Station 19.

13. Anolis capito, Peters.
Rio Frijole.

14. Amiva præsignis, Bd. Gird.

OPHIDIA.

15. Spilotes corais, L.; subspecies melanurus, Dum. Bibr.

16. Xenodon angustirostris, Peters.
Camp Santa Margarita.

17. Sibon annulatum, Linn.
From the Atlantic side.

18. Teleuraspis schlegelii, Berth.
From the Atlantic side.

Total number of species obtained by Dr. Bransford, eighteen.

INDEX OF MAPS AND PLANS ACCOMPANYING THE REPORT OF THE UNITED STATES SURVEYING EXPEDITION, 1875.

ISTHMUS OF PANAMA.

1. General map of the Isthmus of Panama, showing the locations of the proposed ship-canal and its feeder.
2. Profile of the proposed ship-canal, with elevations, cross-sections, &c., of culverts and viaduct.
3. Plan showing the site of the proposed feeder.
4. Plan of the proposed artificial basin.

REPORT OF A SURVEY

OF THE

PROPOSED ROUTE FOR AN INTEROCEANIC SHIP-CANAL

BY WAY OF THE

ATRATO, NAPIPI, AND DOGUADÓ RIVERS,

IN THE

CANTON OF CHOCO, STATE OF CAUCA, UNITED STATES OF COLOMBIA.

BY THE UNITED STATES EXPEDITION OF 1875,

Lieutenant FREDERICK COLLINS, U. S. N., Commanding.

CONTENTS.

PREFACE.

The first instrumental examination of the proposed route for an interoceanic ship-canal by way of the Atrato and Napipi Rivers was made by the United States expedition of 1871, under the command of Commander Thomas O. Selfridge, U. S. N. A more extended examination was made by the expedition of 1873, under the same commander; in both cases the surveys being confined almost altogether to the beds of streams.

The following pages contain a digest of the results of the actual survey of a line from the Atrato near the mouth of the Napipi, to the Pacific at Chiri-Chiri Bay, made by the United States expedition of 1875, with such additional matter as has been thought necessary to give a clear idea of the subject to those who may not have seen the report of Commander Selfridge.

INSTRUCTIONS.

NAVY DEPARTMENT,
Washington, D. C., December 9, 1874.

SIR: You will proceed in the steamer of the 2d January, 1875, from New York to Aspinwall, with the officers who will be ordered to report to you for duty, with instruments and necessary stores, provisions, &c., for the execution of these instructions, as far as may be practicable. At Aspinwall you will find the Canandaigua or some other vessel, to whose commanding officer you will report your arrival, and show him these instructions, furnishing him at the same time with a copy. He is instructed by other orders to proceed with you, the party under your command, and the instruments and stores, on board the Canandagua or other vessel detailed for the purpose, to the mouth of the Urabá; thence to have conveyed the party under your command, with instruments and stores, up the Atrato, in the steam-launch, towing as many cutters or boats as may be necessary to convey them to the mouth of the Napipi; to leave you, your party, instruments, and stores at any desired point in that vicinity, and any boat selected by you, other than the steam-launch, for your use. He will be further directed to return to the mouth of the Urabá on the 15th day of April next, to which point you will proceed as soon thereafter as the execution of your instructions will permit, or when the rainy season shall put a stop to further researches.

The objects you will have in view are as follows:

1st. A continuous line of levels over the hypothetical establishment of Commander Selfridge of the profile for an interoceanic canal, or in its immediate vicinity, as may afford the best line; the accurate measurement of distances and record of courses: carefully marking by "blazing" (scarifying) trees the actual route traversed, and cutting upon the trees at intervals of half a mile or less the elevation above some bench-mark and the number of the tree; the bench-mark to be on the Atrato near the mouth of the Napipi.

2d. Note carefully all water-courses crossed over on the line of best levels for a canal, the probable quantity of water emptied within a given time after heavy rains, and the dimensions of the culverts necessary to meet all possible contingencies from floods.

3d. Establish the exact position found best suited for the building of a dam across the Napipi; its length between hard grounds forming its terminations; its height as found necessary to bank up the waters to any given point above at which it is proposed to cross the river, and a careful examination to determine what character of work may be found necessary to prevent the precipitation into the canal-bed of the *débris* brought down by floods. It is essential to ascertain also the relation in elevation of the present bed (bottom) of the Napipi at the proposed crossing with that of the proposed canal at that point.

4th. The deep cuts to be well defined by measurements of distances; the point at which the proposed tunnel will begin; the distance in a direct line through to be ascertained by a series of triangulations, or, if that may not be practicable, by measured distances, levels, and courses to some given point on Chiri-Chiri Bay, or wherever the Pacific terminus may be located.

5th. The location of the locks proposed in the ascent, and more especially in the descent to the Pacific, and the natural foundations for them as far as can be ascertained by boring or by any other practicable means.

6th. Borings will be made at intervals of a mile, and nearer when deemed advantageous, over the line as located by you.

7th. As close an estimate as possible of the amount of water that may pass over the cross-section of the Napipi where the canal will be located, and the velocity of the current during the heaviest floods observed; also careful observations of the quantity during the dry season at different times.

8th. Provide yourself with a rain-gauge, and note daily the rainfall, and in heavy showers the time and amount of fall.

9th. A careful examination and inquiry to ascertain where suitable clay for puddling, lime and stone for construction, and other necessary material can be obtained.

10th. The original data to be carefully preserved in relation to all of the points presented.

11th. The close observance and ascertainment, by inquiry or otherwise, of the amount of weather yearly that would usually be found available for the construction of a ship-canal, and in this connection, in brief, whatever advantages or disadvantages exist locally favoring or interfering with the construction of an interoceanic ship-canal.

The questions you go to solve are plainly stated; the manner of execution and the arrangements for it are left to you. Your long experience on the Isthmus will enable you to provide as far as possible against untoward contingencies, and to avail yourself of the services of the natives as far as they can be made available.

Upon the completion of this work by the 15th of April, or otherwise as soon thereafter as the rainy season renders it necessary, return with your party to the mouth of the Urabá, embark on board of the vessel directed to await your arrival and to carry yourself and party to Aspinwall, where you will make the necessary arrangements to return to the United States; proceed in person to Washington with such of your party as may properly be employed in collating the information obtained, and direct the others to proceed home, report their arrival to, and await orders from, the Department.

Very respectfully, your obedient servant,

GEO. M. ROBESON,
Secretary of the Navy.

Lieut. FREDERICK COLLINS,
United States Navy.

REPORT OF LIEUT. FREDERICK COLLINS,
COMMANDING EXPEDITION.

NAVY DEPARTMENT,
Washington, D. C., December 20, 1875.

SIR: I have the honor to submit the following report of the operations of the expedition engaged, under the direction of the Department, during the past winter, in surveying the valleys of the Napipi and Doguado Rivers, in the State of Cauca, United States of Colombia, together with a discussion of the results obtained as bearing on the question of the practicability of constructing an interoceanic ship-canal in that locality.

Agreeably to the Department's special instructions of the 9th December, 1874, I sailed on the 5th of January last from New York for Aspinwall, with the necessary instruments, stores, &c., and the following officers, who had been ordered to report to me for duty: Lieut. J. G. Eaton, United States Navy; Lieut. J. T. Sullivan, United States Navy; Lieut. S. C. Paine, United States Navy; Assistant Surgeon Ernest Norfleet, United States Navy.

On the 14th we arrived in Aspinwall. On the 18th the United States steamer Canandaigua, detailed by the Department to transport the expedition to the Gulf of Urabá, came in, and I reported to the commanding officer, Capt. Edward Barrett.

On the same day, Ensign H. H. Barroll reported to me for duty, he having been transferred to the Canandaigua for that purpose by Rear-Admiral Mullany, in accordance with telegraphic orders from the Department, prior to her sailing from New Orleans.

Captain Barrett was ready and anxious to proceed at once, but we were unfortunately detained by the non-arrival of a box of instruments that failed to come in the steamer with the rest of our stores, although they had all been landed on the company's dock in New York four days previous to the day of sailing. This compelled us to await the arrival of the next steamer. But the time was put to good use in carefully ranging our instruments and in practicing all hands in the work before us.

On the 28th, everything being in readiness, we repaired on board the Canandaigua, and she got under way for the Gulf of Urabá. At 5.30 p. m. on the 30th we came to anchor off the Coquito mouth of the Atrato. At daylight on the following morning Lieutenant Sullivan and myself went over to the little village of Turbo, on the eastern shore of the gulf, to arrange for the transportation of our mails, and also for securing a quantity of the coal known to exist in that region, in order that its commercial value might be tested. At noon we returned to the ship. During our absence the kindness of Captain Barrett and his officers had enabled Lieutenant Eaton to prepare everything for our departure. All our stores had been snugly stowed away in the launch and first cutter, and the little steam-cutter, with all the coal she could carry, was ready for towing us to our destination, 160 miles up the river; a task for which she looked totally inadequate, and her failure was confidently predicted by all parties.

At 1 p. m. on the 30th of January we shoved off; our party consisting of the officers already named; a detail of five men from the Canandaigua; an interpreter and rodman, whom I had shipped in Aspinwall; and twelve men, under Master Richman and Assistant Engineer Herwig, to take the boats back.

Our trip up the Atrato was tiresome in the extreme, the boats being so completely filled with

our stores that little chance was left for comfortable quarters either by night or day. The little steam-cutter proved, as had been anticipated, barely equal to her task, and, with frequent stoppages to clean fires and fix up generally, she was scarcely able to tow us against the rapid current at the rate of three knots over the ground. We had every day for a few hours favorable winds, and always made sail when it would draw, thus relieving the steam-cutter considerably. We stopped at but one of the three villages that are to be found on the Atrato below the Napipi. This was at Sucio, the first of the three to be met in ascending the river and the most important. There we were well received by the alcalde and custom-house officials. The alcalde informed us that he had instructions from his government to afford the expedition every assistance in his power. I expressed my appreciation of this kindness, but declined other assistance than a supply of good wood for the steam-cutter, which was obligingly furnished and proved very acceptable. On account of the large quantities of drift-wood that were floating down the Atrato, and the fact that the steam-cutter (an old iron one) was pretty well rusted out, I did not think it prudent to run upstream after dark, so we came to anchor every evening just after dusk, getting under way in the morning an hour or so before sunrise. While thus at anchor we made experiments with the current-meter, to ascertain the velocity of the current in the Atrato. The mean of our experiments showed a surface-current of 183.5 feet per minute.

At 5 p. m. on Friday, February 5, we reached the mouth of the Napipi, having been under way in all about fifty-nine hours. The next morning, accompanied by Lieutenant Sullivan, I started for the village of Vejia del Fuerte, about fifteen miles farther up the Atrato, for the purpose of engaging laborers. Not wishing to delay the boats, we took passage in a native canoe. Lieutenant Eaton was left with directions to discharge all our stores as quickly as possible, and turn the boats over to Master Richman to return to the ship.

In Vejia I found no difficulty in securing as many laborers as I wished. I selected twelve of the best, most of whom had worked with us before. With these I made the following agreement: Each was to receive $20 per month and $5 in lieu of the ration with which they had been furnished on the previous expeditions. With this sum they were to subsist themselves entirely, and the *patron* was to be responsible that they were kept duly supplied. In addition, I promised to each who should give perfect satisfaction $5 per month extra. This was good pay, but it gave us the advantage of being at all times able to command the best men in the country, and the moment one gave cause of complaint he was discharged and his place supplied by a better man. We were thus enabled to keep them up to their work much better than on former occasions. The arrangement of paying them a certain sum with which to subsist themselves, instead of furnishing them food from our own supplies as had been done previously, worked admirably. The plan was suggested by Commander Selfridge as desirable, in order to decrease the weight of supplies to be transported up the Atrato. It not only did this, but it saved us no little labor and annoyance almost every day. The natives were better satisfied with the food to which they were accustomed, and if their supplies ran short they could blame no one but themselves. Finally, the arrangement was an economical one. Not only was the expense of transporting a large amount of provisions saved, but the original cost of the "Darien ration" is from two to three times the amount paid in its stead. I also engaged at the same time six canoes, to be paid for at the rate of $5 per month. I subsequently learned that it would have been cheaper to buy the canoes outright, since a good one could have been had for about $15, and at the end of the survey could have been sold back for about half price.

On Sunday Master Richman left with the boats to return to the ship.

On Monday, February 8, we started up the Napipi with what stores our canoes could carry. That night we made camp on the first northerly bend of the Napipi, from which point I proposed commencing work. It was then my intention to work from this point to the Atrato, about five miles distant in a straight line, and then to recommence at the same point and work westward. This plan, as will presently be seen, circumstances compelled me to change.

On Tuesday, February 9, party No. 2 was organized for carrying on this portion of the work. It consisted of Lieut. J. G. Eaton, commanding, Ensign Barroll, and Assistant Surgeon Norfleet, four seamen, and twelve natives, with four canoes. Lieutenant Sullivan was at this time engaged in transporting our stores up the Napipi, with a gang of natives and a sufficient number of canoes

engaged temporarily for this purpose. It was arranged that whenever his other duties permitted he was to assist Lieutenant Eaton in making reconnaissances.

Party No. 2 at once began the work of surveying toward the Atrato, but before the end of the first day's work they struck such swampy ground as absolutely to prevent further advance in that direction. It was therefore determined to leave that portion of the work till toward the close of the dry season, in hopes that it might then be found in better condition, and to begin at once surveying to the westward. This was done on the following day. On the same day, accompanied by Lieutenant Paine and all the members of the expedition not otherwise employed, I started for the junction of the Merindo and Napipi, to make the necessary surveys for the dam proposed for crossing the Napipi and for developing the character and extent of the country that would be thus overflowed.

On the evening of the 12th we arrived, and established headquarters in a negro house situated opposite the mouth of the Merindo. The 13th was occupied in setting up and adjusting our surveying and meteorological instruments. In the afternoon a careful measurement of the cross-section of the bed of the Napipi below the junction was made, and a series of experiments to determine its volume commenced. In these experiments the velocity of the current was determined by means of a delicate tachometer.

From this time till the 4th of March I was occupied in making the necessary surveys and reconnaissances in connection with the dam and basin and in daily observations to solve the question of water supply. On that day I started, working eastward on the main line of survey to join Lieutenant Eaton, who had all the time been working westward.

I was desirous of testing the practicability of running a straight line from the point of crossing the Napipi to the Atrato. I therefore began following the general direction of the line indicated by Commander Selfridge, which line was laid down on our field-maps. For the first two days, following this line, we found fairly level country. We then began to cross steep spurs, getting each day higher and more numerous. As we encountered these hills, I kept turning the line to the southward, hoping to avoid them. I also made what reconnaissances time would permit to the northward, but invariably found the country worse in that direction. On the 9th, the country became so bad as to be impracticable for canal purposes, and it became evident that the lowland, if any existed, must be looked for close to the river. I therefore abandoned the attempt to continue on that line, and on the 10th moved down river about eleven miles, and established camp on the site of my old camp No. 9 of the survey of 1871. From this point I made another attempt to run a straight line to the eastward, but with no better success than before. As we receded from the river we began to meet hills, which grew worse and worse as we proceeded. I pushed the survey for three days, and then, becoming fully convinced that to find good ground the river must be followed closely, I determined to join Lieutenant Eaton at once, start him on the swamps, about which I was getting anxious as there were signs of an early setting in of the wet season, and to start with the rest of the force a new line that should follow the river closely, and thus avoid, possible, the hills encountered in such profusion in the back country.

Accordingly, on Sunday, March 14, I joined Lieutenant Eaton at his camp No. 4, which I christened Camp Relief. During the month past his party had undergone severe labor. He had found but little level land, most of the spurs in that part of the country butting directly upon the river, so that he had found it impossible to avoid them by turning either to the north or the south. The work of his party had therefore been exhausting and their progress slow. Their work, however, had been done most thoroughly, and with the assistance afforded by Lieutenant Sullivan he had been able to develop the topography along the line of survey in a most satisfactory manner. Fo a detailed account of his work I would refer to his report, marked A, in the Appendix.

The parties remained together at Camp Relief till Monday, the 17th; Lieutenant Eaton being occupied in bringing the line of survey up to that point, and the rest of the force in reconnoitering the country ahead, to determine the best ground for the line to follow.

On the 17th a new arrangement of parties went into effect. Party No. 2, then consisting of Lieutenant Eaton, Ensign Barroll, three seamen, and four natives, went down the river to attempt the survey of the swamps. Party No. 1, consisting of myself, Lieutenants Sullivan and Paine, Assistant Surgeon Norfleet, three seamen and twelve natives, continued the main line to the west-

ward. By keeping close to the river, it was found possible, as I had hoped, to avoid in this part of the line almost altogether the steep spurs that had so troubled us on the way down. The large force now at my disposal enabled me to have the ground thoroughly reconnoitered, and we succeeded in keeping the line for the most part clear of the hills and in level or gently undulating ground. Owing to this cause, the extremely favorable weather, and the masterly manner in which the gradienter was handled by Lieutenant Paine, our progress was rapid, and on the 31st of March the survey was brought up to headquarters at the junction of the Merindo.

Party No. 3 was now organized, to carry the survey up the valley of the Doguado and over the divide to the Pacific. It consisted of Lieut. J. T. Sullivan, commanding; Lieut. S. C. Paine and Assistant Surgeon Norfleet; two seamen, and six natives. I remained at headquarters, with one seaman, unfit for active duty, as cook, and with the assistance of two natives, made reconnaissances, developing the character of the country in that vicinity.

On Tuesday, April 6, Lieutenant Eaton and party arrived at headquarters, having, after extraordinary exertion, succeeded in carrying a line of survey through the swamps to the Atrato. The appearance of this little party was sufficient evidence of the hardships they had undergone. All hands had been sick with fever, and all but Ensign Barroll and one man were still unfit for duty. The next day Lieutenant Eaton was taken with a relapse of the fever, and became seriously sick. Headquarters now presented the appearance of a hospital. Four out of the seven members of the expedition there present were confined to their cots, and two of the others were barely able to be about. For some days, therefore, little work was done. I occupied myself with reconnaissances, and Mr. Barroll, unable to do anything else, plotted up the charts and worked up the field-books.

On the 13th, Mr. Barroll and two of the men, having sufficiently recovered, began a survey toward the river Cuia, for the purpose of obtaining data for the aqueduct to bring the waters of that stream to the summit-level of the canal. On the 20th, this survey having advanced about half-way to the Cuia, I established a camp on the brook Cuita, and took charge of the remainder of the work, with Mr. Barroll, two seamen, and four natives. No sooner had I commenced work than the seaman acting as rodman became so seriously sick that I feared for his life, and our little party seemed effectually crippled. At this juncture Mr. Barroll, always ready for hard work, volunteered to do double duty as recorder and rodman, and in this way, wading waist-deep in water all day, and with torrential rains every night (though fortunately our little hut of leaves did not leak badly), the survey was pushed till the 25th, when sufficient data for our purpose had been acquired, and we returned to headquarters. Here I found dispatches from Lieutenant Sullivan, reporting the progress of his work. His party had had a severe experience in carrying the survey up the rugged valley of the Doguado. In accordance with instructions, he had kept the line on the right bank till a height at which it was supposed tunneling would have to be resorted to had been attained. To facilitate the progress of the survey, the line had then been carried to the bed of the river, and up the bed till opposite Chiri-Chiri Bay. There he had crossed the divide at an altitude of 778 feet, and at the time of writing he expected to connect with the bench-mark of 1873 on the Pacific beach, on the 26th. A full account of his proceedings will be found in the Appendix, marked B.

On the 28th, I went with Lieutenant Eaton to the point where Lieutenant Sullivan's line joined the bed of the Doguado. I found that his line had been carried farther from the river than I had supposed, the error arising from a combination of several causes, but through no fault on the part of Lieutenant Sullivan, and that further surveys would be necessary to determine with precision the best line for the canal to follow to the tunneling-point. At this time I supposed that we had still two weeks left for work, as I had received on the 8th of April a communication from the Department stating that, in accordance with my suggestion, the orders to the commanding officer of the Canandaigua had been so changed as to delay her arrival in the Gulf of Urabá till the 15th of May. Acting on this supposition, I was on the point of dispatching directions to Lieutenant Sullivan to stop on his return and make additional surveys in the valley of the Doguado, when, to my surprise, Master Richman arrived at headquarters reporting the Canandaigua's boats awaiting us at the mouth of the Napipi.

It appeared that Captain Barrett had received neither the communications from the Department

nor the letters I had sent him, and had therefore proceeded to the Gulf of Urabá, in accordance with his original orders, on the 15th of April. Unfortunately, also, the ship was nearly out of bread, and the instructions to Master Richman were to wait but five days, two of which he had already consumed in reaching us after leaving the mouth of the Napipi. I at first thought I should be compelled to let him return without us; but, upon reflection, I concluded that it would not be the part of prudence to do so. I knew that by that time Mr. Sullivan must have connected his line, and that the main labors of the survey were finished. Our provisions were nearly exhausted; the wet season was setting in; many of the party were sick; all were showing more or less the effects of our long siege, and our natives were tired of the work, discontented, and anxious to return to their homes. Under these circumstances I did not think it right either to continue the exposure of the party for an indefinite period or to put the Department to the expense of sending twice for us, simply for the purpose of putting the survey in a little more satisfactory shape.

Instead, therefore, of the letter directing Lieutenant Sullivan to stop when on his return for further work, I wrote him to cease work at once on the receipt of the order, to abandon everything not valuable or actually necessary, and to return with all dispatch to headquarters. This order I dispatched that night at ten o'clock by two native messengers. promising them a handsome bonus if they would put it in Lieutenant Sullivan's hands within twenty-four hours.

The next morning, the 29th, I started with Ensign Barroll and four men to employ whatever time might be left in getting additional data concerning the valley of the Doguado. Lieutenant Eaton was left at headquarters to prepare everything for starting down river as soon as Lieutenant Sullivan should arrive.

At 3 p. m. on the 30th a messenger reached me from Lieutenant Sullivan, saying that he had reached my camp on his way down. I therefore returned at once, and that night all hands were together at headquarters.

On the morning of May 1 we started for the mouth of the Napipi, which we reached at 10 a. m. on the 2d. I immediately proceeded to Vejia del Fuerte to pay off the natives and settle outstanding bills, and, this accomplished, returned to the mouth of the Napipi, ready for a start down the Atrato.

Accordingly, at daylight on the morning of the 3d we began our journey down that river. The steam-cutter worked even worse than when towing us up, but with the powerful current in our favor we made good progress, and at eight o'clock on the morning of the 5th we were once more on board the Canandaigua. Lieutenant Sullivan's time—five days—from the Pacific to the Gulf of Urabá is, I have no doubt, the quickest on record.

While the Canandaigua was getting up steam I went with Lieutenant Sullivan to Turbo to settle bills and get the specimens of coal we had ordered. Much to our disappointment (but not surprise, knowing the character of the people), no attempt had been made to fulfill this contract, and, as we could spare no further time, we were obliged to come off without the coal.

At noon of the same day the Canandaigua steamed out of the Gulf of Urabá, and on the 7th came to anchor off Aspinwall.

On the 16th we sailed in the Pacific mail-steamship Acapulco for New York, arriving on the 25th; when, in accordance with my instructions, I ordered the officers to proceed to their homes and report by letter to the Department.

On the 27th I reported in person the return of the expedition, and on the 31st was detached from the command and ordered to special duty in connection with the preparation of the data obtained.

On consulting with Commodore Ammen, Chief of the Bureau of Navigation, as to the best form in which to present the information acquired by the expedition, it was thought preferable to prepare estimates of the amount of work that the construction of a canal by this route would involve; and, for the purpose of comparison, to calculate from these estimates its probable cost, allowing the prices that had already been allowed for similar proposed work elsewhere.

I have, therefore, the honor to present herewith such estimates, with a detailed description of the works supposed to be necessary to the successful operation of a ship-canal in that locality. With reference to the plans presented, I would say that they are designed simply to present in a more intelligible form than could otherwise be done the character of this proposed canal-route. In

regard to details, such as best form and dimensions for canal-prism in rock and earth, and for a tunnel of the magnitude of the one here proposed, it is fully recognized that these are open questions. Those that have been adopted as the basis for these estimates (which are substantially the same as those proposed by Commander Lull for the Panama route) are believed to be, all things considered, the best adapted to the required conditions, and to afford a fair idea of the work that would be required in actual practice, as nearly as that may be done with the limited data at hand.

As for cost, it has already been remarked that the prices here allowed are the same as have been allowed at Nicaragua and Panama. It is altogether likely that some of these are insufficient. As an offset to this, it should be remembered that a more detailed survey would, without doubt, result in the amelioration of some of the unfavorable conditions that have entered into the accompanying estimates.

The general plan which has been followed is that proposed by Commander T. O. Selfridge. It is to follow the left bank of the Napipi to its junction with the Doguado; there to cross by means of a dam of sufficient height, and then to follow the right bank of the Doguado till the cutting becomes so deep as to require tunneling; then to pass under the dividing ridge by means of a tunnel, coming out in the valley of the Chiri-Chiri River, in which are to be situated the locks necessary to descend to the Pacific Ocean at Chiri-Chiri Bay.

In treating of the proposed work, I have, for convenience of reference, divided my remarks into twelve heads to correspond with the paragraphs of my instructions, as follows:

I. General description of the country along the proposed line; description of the proposed work; manner of conducting the survey.
II. Culverts and works to protect the line from floods.
III. The dam and basin for crossing the Napipi.
IV. The tunnel and pointing-basin.
V. Locks.
VI. Characteristics of soil, &c.
VII. Water-supply and aqueduct from Rio Cuia.
VIII. Meteorology and climate.
IX. Materials for construction.
X. Harbors.
XI. Local advantages and disadvantages; general remarks.
XII. Synopsis of estimates.

SECTION I.

GENERAL DESCRIPTION OF THE COUNTRY IN WHICH THE PROPOSED LINE IS SITUATED; MANNER OF CONDUCTING THE SURVEY; DESCRIPTION OF THE PROPOSED CANAL.

The proposed canal-route now under consideration lies within the territory of the State of Cauca, one of the United States of Colombia. The area of this State is about 68,300 square miles, and it is divided into four cantons: Buenaventura, Pasto, Popayan, and Choco. The last of these occupies the extreme northwestern portion of South America, contiguous to the Isthmus, and within its limits lies the Napipi canal-route.

PHYSICAL FEATURES.

The topography of this portion of South America does not appear to be generally understood. It is commonly supposed that the Andes are continuous with the Cordilleras of the Isthmus. But the Andes proper leave the Pacific coast at about the third parallel of north latitude, and, dividing into three branches, terminate on the southern shores of the Caribbean sea. The Cordilleras of the Isthmus sweep to the westward in the vicinity of the eighth parallel of north latitude, and extend along the Pacific coast in Choco as a range of comparatively low hills. The space inclosed between these hills and the westernmost range of the Andes, known as the Antioquian Mountains, affords a double water-shed; one drained to the southward into the Pacific by the San Juan River, the other to the northward into the Atlantic by the Atrato. The Atrato, which plays so conspic-

uous a part in the canal scheme now under consideration, rises in about 5° 20′ north. It flows in a northerly direction parallel to the Pacific coast, and empties into the Gulf of Urabá through a delta comprising thirteen mouths.

The mouths of the Atrato are at present obstructed by a bar on which there is only about 4 feet of water. But within this bar the channel is broad and clear, and, as far as the confluence of the Napipi, not less than 28 feet deep in any part at the lowest stage of the river. It was surveyed as far as the Napipi by Commander Lull in 1871, and in 1873 Commander Selfridge continued the survey as far as Quibdo. Above the Napipi it was found to shoal considerably, but six feet may be carried as far as Quibdo at the lowest stage of the river. Throughout this distance the Atrato is truly a magnificent river. Its valley was evidently once an arm of the sea, that has been gradually filled up by the denudation of the hills on either side, and by the decay of the vast masses of vegetable matter that yearly spring up and thrive in rank luxuriance under the favoring influence of copious rains and a vertical sun. In the lower portion of the valley this process is still going on, and there are vast swamps extending for miles upon each side of the main channel, filled with the coarse *camalote* grass growing in many places so thickly as to prevent the passage of boats, and presenting the appearance of an immense meadow; yet underneath a deep strong current sets steadily seaward.

It is not, indeed, before reaching the village of Sucio, some sixty miles from its mouth, that firm banks will be found to the Atrato; but beyond that point they extend in unvarying monotony 10 to 15 feet high, and with hardly a hill or sign of high land in any part. On both sides of the river a level country stretches back for some miles. Near the river this country is frequently inundated during the wet seasons, and it is in consequence filled with swamps and *cienegas*. As it recedes from the river, the ground becomes higher and breaks up into hills. The firm ground is everywhere covered with an unbroken forest, filled with precious woods suitable for the builder and the cabinet-maker, and with rubber-trees and valuable dye-woods of various sorts.

All our observations agree in showing the physical features of this country to be wonderfully systematic. From the main "divide" between the valley of the Atrato and the Pacific, which skirts closely the shore of that ocean, come down to the eastward long spurs or ridges, which form the divides between the various westerly tributaries to the Atrato. These ridges send off smaller spurs to the northward and the southward, and these divide again and again, till the whole country is overspread with ranges of hills running the one into the other like the veins on a leaf. A detached hill is rarely to be met. These ridges have usually very narrow crests, and their sides descend abruptly, often precipitously. Their crests, rising and falling with gentle slopes, always afford good ground for walking. They are, therefore, used by the natives for their roads or trails almost exclusively, they having long ago learned that the longer way around, with a good road, is a surer way home than the shorter, which, cutting across the ridges, presents a succession of steep and slippery hill-sides.

Immediately along the line of survey the country naturally divides itself into four sections as regards its topographical characteristics. First, there exists from the banks of the Atrato for some five miles to the westward a flat swampy region of a lower average level than the banks of the adjacent streams. During the wet months this region is frequently inundated to a considerable depth. During the dry seasons its more elevated portions become sufficiently firm to be passable, but those of a lower level always remain open-water swamps or miry morasses. This portion of the route is in fact the delta of the Napipi, since it is bounded to the northward and westward by a second mouth of that river, called the Braso Muriel, while a third, the Palmerito, flows through its central part. It includes in the portion near the Atrato several large *cienegas*, or lagoons, which during the wet season are lakes with an average depth of five to six feet of water, but which become more or less dried up as the rains lessen. These *cienegas* at one time threatened to put a stop to our surveys of that portion, but by the indefatigable exertions of Lieutenant Eaton an isthmus, or natural causeway, as he terms it, was discovered, which was of sufficient firmness to permit the passage of his party. For an admirable description of this dismal portion of our route and of the difficulties encountered in surveying it, I would refer again to Lieutenant Eaton's report in the Appendix.

But one hill was discovered in this portion of the route, and that a small one near its center.

It is doubtless an upheaval of the underlying rock, against which and around which the *debris* brought down by the river has accumulated to form the delta.

The vegetation of this section is peculiar. Away from the banks of the streams there are comparatively few trees, and they principally the *quita sol* palms, covered with long sharp thorns, and affording little shade. The ground is covered with coarse swamp and hummock grass, that, with its saw-like edges, cuts like a knife.

Some miles of river navigation might be saved by turning the canal-line to the northeastward through this section, as is represented by the broken lines on the accompanying map (Plate II). But I had no time to go actually over the ground, even if that had been found possible, and in projecting a ine upon which to found estimates deemed it necessary to follow the actual line of survey as closely as possible.

The second topographical section extends from the Braso Muriel to the hills in curve No. 8, a distance of about six miles. This section is characterized by the extension of the spurs of the divide between the Opogado and Napipi Rivers to the very banks of the latter, rendering it necessary to cross them continually with the line of survey. Extended reconnaissances were made to determine the practicability of flanking these hills by a detour to the northward, but in almost every case they were found to increase in height as they receded from the river, proving to be parts of the system just described rather than detached hills that might have been flanked. When, therefore, these hills butted on the river, there was no course left but to cross them. Some could, doubtless, have been crossed more favorably than they were, as our limited time and small force did not enable us to be always sure that we were on the best ground.

In laying down the canal-line after the field-work had been plotted it was found that, by diverting the Napipi in some of its sharp northern bends and carrying the canal-line to the southward, a number of these hills could be avoided. The line was, therefore, laid down in that manner, and the accompanying profile shows it as thus amended. Ample allowances have been made where the canal-line thus deviates from the line of survey, so that no doubt can exist that the reality is, if anything, more favorable than the representation.

The third topographical section extends from the western limit of the second to the point where the proposed canal is to cross the Napipi River, near the junction of the Merindo and Doguado. In this section the spurs or ridges extend but rarely to the river-banks, so that by keeping the line well down to the southward it was found possible to avoid them. Our profile, therefore, of this section shows level or gently undulating ground, with no elevations of any considerable magnitude.

The fourth topographical section extends from the point of crossing the Napipi to the Pacific coast. It is characterized by being extremely broken and by the great height of its ridges as compared with those of other sections.

For the first five miles of this section the line of survey followed the right bank of the Doguado. The line was then carried to the river-bed to facilitate the progress of the survey. It held the bed of the river until opposite Chiri-Chiri Bay, when it struck across the main divide and descended to the Pacific coast on a spur on the left bank of the Chiri Chiri River. The dividing ridge was crossed at a height of 778 feet, the crest of the ridge being but about 4,000 feet in direct horizontal distance from the beach.

The distance between the Doguado and Merindo Rivers is so small and the divide between them is so high, that its spurs extend almost invariably directly to the river-banks. It is therefore impossible to carry a line of survey anywhere up that valley, unless in the river-bed, without crossing these spurs continually. Of course the nearer the line is to the river the less, as a rule, will be the elevation at which they must be crossed.

My instructions to Lieutenant Sullivan, who commanded the party running this portion of the line, were to keep the survey well down toward the river, so as to secure the best ground. This was done as well as the circumstances of the case and the state of our knowledge at the time would allow. But upon obtaining subsequently a correct plot of his survey and of a traverse by myself up the bed of the river, it was found that the line was farther from the river than we had supposed. The difference was that of a few hundred feet only; but on those steep hill-sides a few hundred feet only are required to make a most important difference in elevation.

It became evident, therefore, that our survey in this part could not be accepted as showing

the best line for a canal. Under these circumstances, having a survey of the river made with the same care as that of the main line, I projected the canal-line as close to the river as possible without introducing any curve of a less radius than 2,500 feet, and then approximated the elevation of its various points by adding to the elevation of the river-bed the observed height of the banks, and to this a part of the difference between it and the elevation of the corresponding point on the main line proportioned to its distance from that line.

That part, then, of our profile included between the basin and the eastern portal of the tunnel must be regarded as, to a certain extent, hypothetical. But when it is considered that the projected line lies between two surveyed lines rarely more than 1,000 feet apart, and that most liberal allowances have been made to make sure of being on the safe side, I think there can be no doubt that our profile is, if anything, less favorable than the reality.

INHABITANTS.

The inhabitants of Choco may be divided into three principal classes, viz: Spanish whites, negroes, and Indians. Each of these races has many pure-blooded representatives, and, in addition, there is a large nondescript class, arising from the repeated crossings of the three. The whites, though by far the least numerous, form, by virtue of their superior education and intelligence, the ruling class. The negroes form the bulk of the population, for the greater part of Choco is low, and in the *tierras calientes* the negro flourishes as on his native soil. Those found in Choco are, of course, the descendants of slaves imported from Africa when the country was under the rule of Spain. They live principally along the banks of the Atrato or near the mouths of its tributaries, where they cultivate in their lazy way bananas, plantains, sugar-cane, bread-fruit, and Indian corn. These the rich soil produces almost spontaneously, but the negroes are so little inclined to exertion as to raise barely enough to keep them from starvation, and they would frequently suffer for food were it not for the fish that abound in the Atrato. Their condition is but little superior to that of the Indians, but they are of a more social disposition, and congregate in little villages, where their mode of life exhibits a most incongruous jumble of Spanish, African, and Indian customs. As a race, the men are tall, well-built, and muscular. The women also, when young, are well formed and comely after their fashion; but they develop early, marry young, and, as a consequence, at thirty-five or forty become wrinkled, toothless, horrible hags. They are nominally converts to Catholicism, and designate themselves as *Christianos*, in contradistinction to the Indians, whom they regard as Pagans. They are of a good-natured, happy-go-lucky disposition, little given to quarreling, and serious crime is almost unknown among them. Like most people of their class, they are suspicious of strangers, and considerable tact is required in their management; but when once their confidence is gained they are docile and tractable, and perform their allotted tasks with alacrity and cheerfulness. They possess great skill in wood-craft and in the management of their canoes, and should this canal-route be adopted, their services during the necessary surveys and in clearing the country along the line would be invaluable. As laborers on the canal-works, I think little could be expected of them.

The most interesting class of inhabitants in this province are the scattered remnants of the aboriginal Indians, now known as Chocós or Cholos. It is somewhat uncertain which of the great semi-civilized nations of America these people have descended from. They are thought by some to possess many characteristics indicating a relationship with the *Aztecs* or *Toltecs*. Their nearest neighbors must have been the powerful *Chibchas* or *Muiscas*, and if the boundaries of the territory of that nation are correctly given by Acosta,* it must have included the headwaters of the Atrato. And if it be true that the name *Chibcha* was given by the Spaniards on account of the frequent repetition of the syllables *Chi* and *Cha*,† the continued recurrence of the same syllables in the language of the Chocos (*see* Vocabulary, Appendix E) would appear to indicate, if not establish, a claim to relationship in that direction.

But there is nothing in the appearance or condition of the Indians of the present day to indicate a descent from powerful and cultivated ancestors, however remote. Their condition, indeed, is

* Compendio Historico del Descubrimiento y Colonization de la Nueva Grenada, por el Coronel Joaquin Acosta.
† Antiquities, ethnology, &c., of South America by W. Bollart.

so wretched, that they look up to the miserable negroes as to superior beings. They live scattered about among the hills and mountains, each family by itself, and subsist chiefly by hunting and fishing, tilling the soil even less than the negroes. They are extravagantly fond of intoxicating liquors, and when by any means they can secure the coveted *añisado*, men, women, and children may be seen drunk together. Yet they are not without good qualities, for when engaged as laborers they are faithful, uncomplaining, and industrious. They are also hospitable to the extent of their means, and at their hands the stranger may be sure of nothing but kindness. In physique they are greatly inferior to the negroes, being short in stature and with puny limbs, yet they are capable of enduring great fatigue and exposure without apparent ill effects. They are extremely timid, and express great horror at the idea of war or bloodshed. Though somewhat quarrelsome when in liquor, I have never known their belligerent demonstrations to extend beyond pulling each other about by the hair, for which amusement their long coarse locks are admirably adapted. And even this mild method of combat is confined mainly to the women, whose respective lords look on with the greatest composure, apparently indifferent to the issue of the battle. On one occasion, however, I remember to have seen an old priest, or *jaybana*, endeavor to interfere, but he was knocked out of time with such celerity by the united efforts of the fair combatants as to have no stomach for further intervention.

They are so averse to conversation on the subject of religion, that I found it impossible to draw from them directly anything relating to it. I learned, however, the following particulars from a very intelligent young negro who had been much among them and was acquainted with their language. If his account of their daily anticipation of the arrival of a god to set up a kingdom on earth is correct, the fact is certainly a most curious one. According to his account, the Indians worship a god whom they call *Jay* (pronounced ha-ee), and whom they represent by a rude figure of an animal. I have seen them wearing these in their hair, but was unable to make out what animal they were intended to represent. Their priests they call *jaybanas*. They have no stated season for holding religious services, but generally hold them on the serious illness of any one, or such special occasions. These services are always held after nightfall and without lights. The *jaybana* recites in a monotonous chant certain legends, and the people listen in silence. Women are admitted to the priesthood, and young boys and girls are kept in training, learning the legends. They expect daily a god inferior in power and dignity to the great *Jay*, who is coming to establish a kingdom on earth.

The attendance of a *jaybana* is considered necessary at funerals, but they marry without ceremony. It is usual for a man to have but one wife, but he may take as many as he pleases.

At funerals the women weep and wail, but it is considered unbecoming in a man to indulge in any manifestations of grief. They set up the cross over their graves, but this is done in imitation of the Christians, and from some superstitious belief in its power to ward off evil spirits, not from any understanding of its symbolical meaning.

RESOURCES OF THE COUNTRY.

A writer in the American Encyclopædia says of Choco that it is distinguished for the poverty of its inhabitants and the inexhaustible abundance of its mineral deposits. I can vouch for the truth of the first half of this assertion, and have unlimited faith in the last.

It has long been known that the headwaters of the Atrato is one of the richest gold regions in the world. All the streams—and their name is legion—that come into the Atrato from the eastward, having their sources high up in the Antioquian Cordillera, bring down this precious metal suspended in their waters. Their gravelly beds and sandy *playas* are rich with gold, which is so abundant as to be carried during the floods of the rainy seasons into the Atrato itself. The means employed by the natives to obtain this gold are, as may be supposed, rude in the extreme. Vein mining is carried on to a limited extent only, and then with machinery of the simplest possible construction. The greater part is obtained by washing the sands of the streams immediately after the subsidence of the floods of the rainy months. In spite, however, of the rude means employed and the desultory way in which the search is carried on by the lazy natives, the annual amount collected is by no means inconsiderable. The greater portion finds its way to Quibdo, the capital and principal town of the province, where, as I was informed by the *jefé municipal*, when in that town in 1873,

there is yearly collected from $200,000 to $300,000 worth. Such an amount as this, considering the circumstances, certainly indicates a richness in those gold regions that promises most profitable returns when the influx of labor and capital shall enable the business to be conducted in a systematic and scientific manner. Besides gold, silver, platina, and other metals are known to exist, though in what quantities I cannot say.

The existence of coal on the eastern shores of the Gulf of Urabá and on the Pacific at Cupica Bay is important in connection with the proposed canal scheme. Specimens of the coal from Urabá were obtained by Commander Selfridge, and the result of its analysis showed it to be of fair quality.* A small specimen of the coal from Cupica was handed to me recently by Lieutenant Norris, by whom it was found in 1873. I submitted it for analysis to the mineralogist of the Smithsonian Institution, and on examination it was found to possess "all the characteristics of anthracite coal." He adds, however, that "it would be hasty to infer that a deposit of anthracite coal may exist at the locality where this was found." (See letter of Professor Henry, Appendix G.)

Among the most important of the many sources of wealth in Choco are its extensive forests, filled with rubber-trees, dye-woods, and beautiful and valuable woods of many species. A list of more than thirty varieties of the latter will be found under the head of materials for construction.

Of the valuable article of rubber, Choco possesses an almost inexhaustible supply. The trees are thickly scattered over an immense area, and each will yield, it is said, a considerable quantity daily for twenty years. But the ignorant negroes, in their short-sighted cupidity, now cut the trees down as they find them, thus securing a larger amount at once and with little trouble, but "killing the goose that lays the golden eggs."

The capability of the rich soil of this region to bring forth in abundance all the varied productions of the tropics does not need to be dwelt upon. Rice, indigo, cotton,† sugar, tobacco, cocoa and fruits of many varieties grow almost spontaneously; and this region is the very home of the plantain, concerning which it is said that ground yielding wheat sufficient for the sustenance of one man will grow plantains for twenty-five men. In a word, it cannot be doubted that in natural sources of wealth Choco is extremely rich.

MANNER OF CONDUCTING THE SURVEY.

The main line was run entirely with two instruments constructed by Würdeman, of Washington, and called "gradienters." These instruments had been in use on the previous expeditions, and had been found admirably adapted to the rapid reconnaissance of open rivers. They also particularly recommended themselves to us when fitting out for the last expedition by the fact that with them the work of survey can be prosecuted with a much smaller force than is required by the transit or compass and chain. The method of measuring distances by a micrometric attachment to the telescope is also an advantage in a rough country that can be readily appreciated. But for a regular and careful survey they are not well adapted. They are most vexatious instruments to run; they are difficult to keep in adjustment, and easily broken. They would be excellent instruments to put on board ships for use in reconnoitering rivers and in the survey of harbors. For any other purpose I would not recommend them. Our experience, however, shows that when carefully handled they will give fairly reliable results. We had no opportunity to run extended lines of check-levels for the purpose of testing the accuracy of our work, but on several occasions during its progress checks were obtained, in some cases lines of considerable length over very rough ground being involved. In each of these cases the disagreement did not exceed five-tenths of a foot, which, it appears to me, is quite as close as could have been expected.

On the line for the aqueduct we connected with the survey of 1873. Here a line more than twenty miles in length was involved, some of which was over as rough ground as it is possible to level over at all, and the discrepancy was between 3 and 5 feet. I can give it no closer than this, as the actual spot on which to connect could not be determined, the mark having disappeared.

* See Report of Professor Baker in the Appendix to Report of Commander Selfridge.

† Two kinds of cotton grow in Choco, and both on trees. One is called by the natives *Algodon de Riñon*, the other *Algodon de Pajarita*. On planting the seeds, but three months are necessary for the tree to spring up and attain a sufficient size to commence bearing. It will then continue to grow until it becomes a large tree, bearing all the while its crops of cotton the year round. The natives spin the cotton into a coarse thread by means of a rude apparatus called the *uso*, but they use it for no other purpose than the manufacture of fishing-nets. The cotton, as compared with that produced in our Southern States, is of little value. (See letter of Commissioner of Agriculture, Appendix F.)

But the nature of the ground admitted no greater limits than those assigned, and the difference was assumed as 4 feet. I therefore conclude that our elevations are sufficiently accurate for a preliminary reconnaissance.

The distances on the main line of survey were in general measured by the micrometer attached to the telescope of the gradienter. Two targets, 5½ feet apart, were fixed on the leveling-rod, and the number of turns and fractions of a turn of the micrometer-screw, corresponding to every horizontal distance of 10 feet between the limits of 40 feet and 500, were determined by a series of careful experiments before leaving Aspinwall. Interpolations were made for the intermediate feet, and the whole was then tabulated in a convenient form for ready reference. In order to test the accuracy of this method of measurement in actual practice, I caused the distances thus obtained to be frequently checked by the standard tape, and the results were such as to convince me that, for a rapid survey over a rough country, it is superior to the common method of chaining. On hill-sides, where the rapid rise or fall necessitated sights of less than 40 feet horizontal distance, we resorted to the tape or chain.

All our elevations were obtained by absolute measurement with the spirit-level, using only horizontal lines of sight. This method was very tedious and laborious when working over the steep ridges so abundant in the region traversed by our line. Our work would have been much lightened and our progress facilitated by measuring the angles of elevation when working over rough ground, but our instruments were not well adapted to that purpose.

Our reconnaissances for developing the topography of the country were necessarily so rapid as to allow only the roughest means of determining distance, direction, and elevation. The former was determined by pacing, the second by the pocket-compass, the latter by the aneroid barometer or hand-level. Neither, of course, can be relied upon except in a very general way; though, after having become expert by much practice, our results often checked with surprising accuracy.

In order to mark the actual route traversed as prominently as possible, large trees were blazed along the line and frequent bench-marks were established. For this purpose a large and conspicuous tree was always selected, a bench or step was cut for the rod to rest upon, and the spot marked with three copper tacks. Above this, a large blaze was cut on the side of the tree, and there was marked in copper tacks the number of the bench-mark and the initial of the officer making it. A full description of the mark was then entered in the field-book. In spite of these precautions, however, I should not be surprised if, a few years hence, it should be found difficult to discover any traces of our work. The cuts on trees in that country soon heal up, so as to become almost indistinguishable, and the bright metal of the copper tacks tempts the cupidity of the natives so strongly that they are very apt to remove them.

The difficulty of finding any of the bench-marks of my survey of the Napipi in 1871, all of which were marked with copper tacks, led me to suspect the natives of removing them; and the suspicion became a certainty when, on visiting a bench-mark made less than six weeks before, I found more than half the tacks gone. I mention these seemingly trivial facts in order that any future explorers may not be surprised if they find difficulty in detecting traces of our work.

Finally, as regards our survey, I may say that we did our best with the means at hand, actuated solely by an honest desire to do our work faithfully and to learn the truth. Pressed as we were for time, the desire to progress with speed was never allowed to interfere with good work. My instructions to Lieutenants Eaton and Sullivan, prefixed to their reports in the Appendix, will show that every precaution to insure good work and a thorough knowledge of the ground passed over was required; and I am sure that my ideas on these points were carefully carried out.

DESCRIPTION OF THE PROPOSED CANAL.

The general plan of the proposed canal has already been indicated. For the convenience of a more detailed description we may divide the canal into four divisions:

	Miles.
Eastern division, from Atrato to "crossing"	20.63
Middle division, from "crossing" to tunnel	4.81
Tunnel division	3 50
Western division	1.30
Total length of canal	30.24

For the first five miles of the eastern division the line lies through swamps, and throughout this region the water-surface is kept below the ground-surface. On reaching firm ground a sufficient number of locks are introduced to bring the water surface well above ground, and by occasional locks at convenient points it is kept above, so that about fourteen miles of the eastern division require embankments. In all, twelve locks, with a lift of 10.3 feet each, are introduced in this division, raising the summit-level to 143 feet above mean tide.

In this division also, by means of twelve culverts and the necessary side drains, the drainage of the northern side of the valley of the Napipi is provided for without the necessity of taking any of it into the canal. In three places in this division the canal has been carried across the Napipi in its sharp northern bends. In these cases the necessary channels for diverting the river from its present bed, as well as for the necessary walls and culverts for carrying the canal across the depression, have been allowed for.

The crossing of the Napipi, to follow the valley of the Doguado, is, as has been stated, to be effected by raising its waters to a sufficient height by means of a dam to be thrown across just below the junction of the Merindo.

From the basin thus formed to the tunnel the middle division extends, lying in the valley of the Doguado. The length of this division is 4.8 miles, and the depth of the required cutting averages 90 feet. For the first 6,000 or 7,000 feet, however, the cutting is light, the deepest cut in that distance being only 45 feet. The length of the deep cutting is from 16,000 to 17,000 feet. The deepest cut is 245 feet, but this is for a short distance only through the summit of a sharp spur. At the eastern portal of the tunnel the cutting is 225 feet in depth. In order to keep the best ground in this division, the river will have to be frequently diverted, from its present bed. Capacious side channels will also have to be constructed to carry the drainage of the steep hill-sides to the basin.

The tunnel required for passing the canal under the dividing ridge and bringing it out on the Pacific slope in the valley of the Chiri-Chiri River has a length of 3½ miles.

The western division includes the portion between the western portal of the tunnel and the line of 26 feet of water on the Pacific shore. Its length is only 1.3 miles, and it is occupied entirely by the "Pointing Basin," by which the change of direction between the tunnel and the valley of the Chiri-Chiri is to be effected, and by the ten locks required to ascend from, or descend to, the Pacific. The harbor at this terminus may also be properly considered as forming a part of this division. It will be found described, with the breakwaters necessary to the protection of the entrance of the canal, in section X of this report.

The following forms and dimensions for the canal-prism have been assumed as best calculated to meet the requirements of the case (*see* Plate VI):

	Feet.
Width at bottom	72
Width at water-surface in earth cuttings	150
Width at water-surface in rock cuttings	98
Slope of sides in earth cuttings	1½ to 1
Slope of sides in rock cuttings below water	¼ to 1
Slope of sides in rock cuttings above water	½ to 1
Width of top of embankments	9
Slope of embankments, interior	1½ to 1
Slope of embankments, exterior	2 to 1
Width of "bench" at 10 feet above water	9
Width of locks inside	60
Length of locks between miter-sills	400

SECTION II.

CULVERTS AND OTHER WORKS TO PROTECT THE CANAL FROM FLOODS.

It is obvious that in a country subject to such excessive rains as is the one under consideration, ample arrangements for providing for the surface-drainage and for insuring the permanency of the canal-works by protecting them from floods are of the first importance.

In considering these questions, as well as all others involving the principles of civil engineering, I have consulted frequently with Mr. Menocal, late chief civil engineer of the Nicaragua and

Panama expeditions, and I have always found him very willing to give me every assistance in his power. But his time has been so fully occupied with his own duties that I could not feel it right to trespass upon it more than was necessary for a very general outline of what was required. He cannot, therefore, be held responsible as indorsing in detail the plans and estimates herewith presented.

I will consider the questions coming under the present head in accordance with the natural topographical division already indicated.

In the swampy section, near the Atrato, nothing more in the way of drainage seems possible than what is already provided by nature. In such a soil it would, as a matter of course, be impossible to carry the water-surface of the canal above the ground. The first section of the canal is, therefore, so planned as to insure 26 feet of water at the lowest stage of the Atrato, and, although three locks are introduced in the swampy region at points where it is believed a rock foundation will be found, the water-surface is not permitted to come above ground till the firm soil is reached to the westward of the Braso Muriel.

It is altogether probable that the whole of this swampy region is often covered with a shallow sheet of water during great rises in the rivers in the rainy months. It is my belief, however, from my own observation and the testimony of the natives, that such inundations are not of long duration. The waters rise rapidly with extraordinary rains, and subside with equal rapidity when the rains cease, to the normal wet-season stage, in which the rivers are confined to their proper beds and the adjacent lands uncovered. It is only the lowest portions, like the *cienegas* near the Atrato, that remain covered with water during the entire wet season.

Whether or no these frequent overflows would prove injurious to the canal is a question for engineers. It appears to me that this portion could be regarded only as a channel-way to be dredged out to the proper depth and width, and constant dredging, for a number of years at least, would probably be required to keep it open. It is quite possible that, in practice, it would be found impracticable to place any locks to the eastward of the Braso Muriel. It is proposed to close this Braso by a wall between the canal and the Napipi, leaving it to perform its functions as a drain, but preventing the passage of water from the river into the canal. It would have been a good idea, though it did not occur to me in season to incorporate it in the estimates, to provide at this point a cess-pool, by means of which water might be taken in during dry seasons to feed the lower locks.

On reaching the firm ground beyond the Braso Muriel, the question of surface-drainage assumes a new aspect. For some fifteen miles the canal-line runs along the northern bank of the Napipi, crossing the various streams that drain that half of its valley. There are two ways by which this surface-drainage may be taken care of without allowing it to enter the canal. If the canal be carried at a high level, the waters may be collected at convenient points by side drains and passed under the canal by culverts into the river. If the canal be carried at a low level, a capacious channel must be constructed along its northern side, by means of which the water will be conveyed to the Braso Muriel, and thence to the Atrato. Both plans involve great expense. The former, for the culverts, which must be massive works; the latter, for the enormous excavation required not only in the side channel, but in the main canal as well.

In the plans herewith presented the two systems are combined. Lock No. 8, which is introduced some 15,000 feet to the westward of the Braso Muriel, is the first one that raises the bottom of the canal sufficiently high to enable the waters to be passed under it, and all to the eastward of this point is drained by a side channel into the Braso.

Immediately beyond lock No. 8 comes culvert No. 1, and from that point to the crossing the bottom of the canal is kept well up, and the waters are collected at convenient points and passed under the canal by the necessary culverts and tributary side drains. For this purpose twelve culverts in all are required, the estimates for which will be found in the synopsis. They are all to be massive structures of hydraulic concrete, with the same interior form and dimensions as the ordinary prism of the canal in rock cuttings, and with arched openings beneath for the passage of the water, varying in number from one to fourteen, according to the requirements of the case. The plan and elevation, as shown in Plate VIII, will convey a better idea of their character than any description.

In considering this question of culverts, I found no little difficulty in carrying the bottom of

the canal at such a level as to give sufficient clearance beneath it, without, at the same time, raising it so high as to require an extension of the culvert-walls for very long stretches.

In a canal with 26 feet of water, Mr. Menocal considers it necessary to prolong the culvert-walls on either side until the bottom of the canal falls 10 feet below the ground-surface. I have not carried this principle out rigorously in all cases, and yet, as the canal is planned on the accompanying profile, the culverts in several cases attain a length of from 600 to 800 feet. Even then I could not feel sure of a clearance of more than 10 feet between the bottom of the canal and the bed of the Napipi, and all the culverts have been planned with that limitation. It was considered necessary to have a thickness of 6 feet over the crowns of the arches, and that left me but 4 feet for the height of the water-passages. In order to obtain the greatest space consistent with safety with this height, I adopted semi-elliptical arches, having a transverse diameter of 20 feet and a semi-conjugate diameter of 4 feet. Each of these gives an area of 83 square feet, and a sufficient number have been introduced to meet the supposed requirements in each particular case.

Plate VIII shows the details of No. 9 as a type of all the others. The following table gives further information:

Details of culverts.

Number.	Length of walls.	Cubic yards of material.	Area of drainage space.	Number of arches.
	Feet.		*Sq. feet.*	
1	620	39, 200	580	7
2	680	51, 280	880	14
3	480	27, 090	166	2
4	570	40, 030	166	2
5	420	25, 410	166	2
6	390	16, 740	166	2
7	360	28, 100	664	8
8	300	23, 200	664	8
9	350	25, 130	580	7
10	450	26, 430	500	6
11*	170	11, 590	166	2
12	850	48, 920	500	6
13	....	2, 489	80	1

* Nos. 11 and 12 are connected by a capacious ditch.

In the valley of the Doguado, the cutting is everywhere so deep that but one way exists of providing for the surface-drainage. By a number of short channels the river can be made to take care of the drainage of the northern slope of the valley. That of the southern slope must be conveyed to the basin by a capacious side-channel, for which, and the necessary walls to keep the river-water out of the canal-bed, estimates have been made.

In the western division one culvert, with its tributary drains, has been allowed for.

DIVERSION OF RIVERS.

In order to avoid high land or long detours, the Napipi must be diverted from its present bed in three places by artificial channels. In one of these places (the sharp bend in curve No. 5) advantage is taken of the favorable configuration of the ground to form a siding, or turnout, by excavating the low alluvial point to the northward of the canal and constructing substantial walls of hydraulic concrete across the depression of the present bed on the south bank of the canal. All these projected works are shown clearly on the accompanying map and require no special description.

In order to keep the canal in the best ground in the valley of the Doguado, that river must be frequently diverted, as shown on the map. Estimates for all these channels, and for necessary walls to keep the river-waters out of the canal-bed, have been made.

In the valley of the Chiri-Chiri it will be found necessary to construct a channel around the pointing-basin for the diversion of that river. The line of this channel is indicated on the map, and the cross-sections of the basin in Plate V show its position in reference to that basin. This channel, the culvert already described, and a drain for draining all the slope beyond the culvert directly

into the Pacific, constitute all the works of the class now under consideration that are necessary in the western division.

The following exhibits the estimated cost of the works just described:

Culverts	$3,031,405
Drains	2,449,667
Diversion of the Napipi	571,717
Diversion of the Doguado	949,189
Diversion of the Chiri-Chiri	89,733
	7,091,711

SECTION III.

THE DAM AND BASIN FOR CROSSING THE NAPIPI (PLATE VII).

It has been stated, in the general description of the canal, that it is proposed to cross the Napipi by means of a dam of sufficient height to bring the bottom of the summit-level above the bed of the river at the point of crossing. My instructions from the Department contained particular directions to fix the proper location of this projected dam with precision.

The conditions of the problem point at once to the junction of the Merindo River as the proper site for this structure, and a glance at the map will show that the topography of that locality is admirably adapted to the purpose.

A ridge of sufficient height, butting on the left bank of the Napipi a few hundred feet above the junction and exposing a bluff of solid rock, affords a convenient abutment for the north end of the dam. Thence it will extend across the bed of the Napipi, which is about 100 feet wide, across a low alluvial point lying between the two rivers, across the Merindo, which is about 50 feet wide, and abut at its south end on a ridge lying parallel to that river and close to it.

The bed of the Napipi shows solid rock all the way across. A boring in the center of the alluvial point showed bed-rock at the same level as that in the river, and I feel safe in assuming that a rock foundation will be found at that depth all the way across. The solid rock is exposed on the bluff at the north end, and a careful examination convinced me that rock exists in the ridge at the south end at a depth of not more than 5 feet.

The extreme length of the dam on the crest is 1,590 feet. The roots, which are to be imbedded in solid rock not less than 20 feet, are formed in steps to follow the slope of the banks, and on the foundation the length of the dam is 1,330 feet. The foundation is to be imbedded 5 feet in solid rock. It consists of a solid bed of hydraulic concrete 6 feet thick by 20 feet wide. On this rests the superstructure, which consists of a shell of coursed masonry in heavy blocks, with a hearting of solid concrete. The dam is backed with a mass of earth excavated from the basin behind it, and thrown up with a slope of 2 to 1. The front of the dam is formed in steps to break the force of the overfall, and an apron of heavy timber resting on bearing piles and filled in below with broken stones extends 55 feet down the river. A wall on each side 5 feet higher than the crest of the dam confines the overfalling water to a width of 1,200 feet, and the same walls, extended down the front of the dam and along the entire length of the apron protect the roots of the dam from the action of the water. The total height of the dam above the bottom of the foundation is 33 feet. Its height above the mean surface of the ground in which it is imbedded for the greater portion of its length is about 20 feet, and its width at that point is equal to that height. The width of the crest is 8 feet. It will raise the waters of the Napipi 25 feet above ordinary dry-season stage. All these details are shown in Plate VII.

In determining the height of this dam, it was proposed to me by Commander Selfridge to make its crest as high as the level of the highest flood ever known on the Napipi, and to make it also as long as possible, in order that, during floods, there should be no great rise in the basin behind it, and, consequently, in the summit-level of the canal. The height of the greatest flood was approximately marked on the wall of a native hut at the junction of the Merindo by its occupant, an old negro, who had lived there a number of years. He had previously pointed out the mark to Captain Selfridge, and showed it also to me. He said that the flood occurred in the month of November, and that it lasted but a few hours.

Taking everything into consideration, I am compelled to doubt its ever having occurred at all.

The height indicated, however, was a convenient one, and I therefore adopted it. It brings the water-surface of the summit-level up to 141 feet above mean tide. In view of the limited water-supply during extraordinarily dry seasons, I subsequently determined to make the dam two feet higher, and thus give a depth of 28 feet in the summit-level and basin, in order that a reserve might be had to draw upon in case of necessity without reducing the working depth below 26 feet. Calculations were therefore made for such a dam, and the height of the water-surface of the summit-level becomes, under ordinary conditions, 143 feet.

Provisions have been made for a rise of 5 feet above the crest of the dam, in case of extraordinary floods, without injury to the canal-works. I do not consider it possible that such a rise as this can ever occur. The greatest rise that took place while we were in the country occurred on the 11th of April, increasing the hourly flow of the Napipi from 340,000 cubic feet on the 10th to 11,169,000 on the 11th.* This fell again to 1,169,000 on the 12th. Such a flood, which would be of frequent occurrence during wet seasons, would, according to the calculations of Mr. Menocal, raise the water above the crest of the dam only 1 foot. A flood of double that volume, then, which would be uncommon, would raise it less than 2 feet; and that one should occur to raise it 5 feet it is impossible to imagine. The cost of this dam is estimated at $616,000. The various items will be found fully set forth in the synopsis.

THE BASIN.

A dam of the height just proposed would cause the back water to overflow an extent of country that I estimate roughly at about one and one-half square miles. A careful line of levels was run up the beds of each of the tributary streams to the point to which its waters would be set back, and reconnaissances were made to develop the character of the country along their banks. The results of these examinations, as exhibited on our map, show the region to be well adapted to the formation of a basin, no retaining-walls being necessary except for a very short distance near the north end of the dam, where the canal enters the basin.

The nature of the topography renders it expedient to bring the canal into the basin at that point, and to leave it again near the mouth of the Doguado. It becomes, therefore, imperative to provide some means for preventing, as far as possible, the precipitation of *débris* brought down by floods into the canal-bed proper, as well as the deposit of silt therein. It is believed that the construction of a basin of the form shown on the accompanying map will accomplish the object. (Plate I.)

The dotted lines show the probable extent of overflow. The broken lines are the boundaries of the area that it is proposed to excavate to a depth of 28 feet below the crest of the dam. The curved sides of this excavation are of such radius that a vessel, not wishing to stop in the basin, may proceed directly through, as in other portions of the canal. The stone wall A B protects that portion of the canal-bed from *débris* and projects sufficiently far into the basin to give the combined currents of the Napipi and Doguado a direction toward the corner C, which direction, indeed, they would naturally take, when of equal strength, as the resultant of their resolution. An eddy would therefore be formed in the corner C, and in it most of the floating *débris* would accumulate, and could be taken care of by a gang of men employed for the purpose. Whatever might escape this trap would go directly over the dam, as there would be no current to draw it in the direction of the canal-bed. Whatever solid matter might be brought down in suspension would of course be deposited in the order of its weight as the currents slackened on entering the basin. It is reasonable to suppose that the greater part would be deposited within the limits of the deep-water area, whence it could be dredged without interfering with the transit of ships. And here it may be remarked that it is only after heavy rains that the waters of those streams are at all turbid. At other times they are as clear as crystal and bear no silt.

The estimates for this basin will be found with the others in the synopsis. It has been made larger than might appear necessary, in the belief that a commodious basin at this point would be of great value in operating the canal. The cost in round numbers is $1,917,000.

* During this rise the surface-velocity was found to be 293.6 feet per minute.

SECTION IV.

THE TUNNEL AND THE POINTING BASIN.

At a distance of 26,000 feet from the crossing, the cutting having attained a depth of 220 feet and rapidly increasing, a tunnel is proposed to carry the canal under the dividing ridge, which at the point crossed by our line of survey, as has been stated, attains a height of 778 feet. A tunnel starting at the point indicated, and coming out on the Pacific slope in the valley of the Chiri-Chiri, would have a length of 18,500 feet, or 3.5 miles.

No tunnel approaching the dimensions of the one here contemplated ever yet having been attempted, its proper dimensions and best form are altogether open questions. The question of its practicability has been fully discussed in the report of Commander Selfridge, and it appears to be conceded that as a mere feat of engineering its practicability cannot be doubted.

I propose to consider the tunnel question here only so far as may be necessary to arrive at a fair approximation to its probable cost, as nearly as that may be done with the limited data we have to work upon. For this purpose I have calculated the cost with different dimensions according to plans kindly furnished me by W. H. Hutton, of Baltimore. He proposes two forms of transverse section (Plate VI), to be used according to the nature of the material to be pierced. First, for good, solid rock, a trapezoidal form, with a segmental arch of 120°, the crown to be 86 feet above the water-surface; a width of 70 feet at water-surface; a depth of 27 feet of water, and sides battered 1 to 20. The arch is to be formed of masonry 5 feet thick at the spring and 3 feet at the crown, the whole to be well backed by concrete. Second, for unsound or badly-seamed rock, an elliptical section, with a conjugate diameter of 70 feet at water-surface and a semi-transverse diameter of 86 feet above water-surface, the section to be continued below so as to give 27 feet of water. With this section the arched lining is to spring from the water-surface with a thickness of 5 feet, diminishing, as before, to 3 feet at the crown.

Both these sections give 1,846 square feet as the area of water-space.

The first plan would require the excavation of 5,279,843 cubic yards rock, and of masonry in the arch 203,498 cubic yards. Estimating the cost of excavation at $5.35 per cubic yard (the price allowed by Commander Selfridge on the authority of Mr. B. H. Latrobe, of Baltimore), and masonry at $20 per cubic yard (for which estimate I have the authority of Mr. Menocal and Mr. S. T. Abert, United States civil engineer, at Washington), and we have a total cost of $32,316,120. Adding to this $163,000 for the necessary shafts—a rough estimate—we have $32,479,120.

The second plan would require the excavation of 5,102,862 cubic yards rock, and of masonry 682,993 cubic yards, giving a cost of $40,960,272. It is, with our present knowledge, quite uncertain what sorts of rock would be encountered in the actual construction of this tunnel. Perhaps in estimating its cost it would be fair to take a mean of the two sums just given. Such a mean would give as the cost of a tunnel 70 feet wide and 113 feet high the sum of $36,801,196.

The necessity for a width of 70 feet is so strongly questioned by some, that I have thought it best to calculate the cost of a tunnel with the same form of cross-section, but with the width at water-line reduced to 60 feet. The height above water remains, as before, 86 feet, but in accordance with a suggestion of Commander Selfridge, the depth has been increased to 30 feet, thus securing greater water-space at a trifling comparative increase in cost. In this plan the area of water-space is 1,765 square feet. With this reduced width the excavation in good rock would be 4,915,397 cubic yards, and the masonry required in the segmental arch would be 199,181 cubic yards. These figures give a cost of $30,443,994.

The elliptical section, with reduced width, would require: excavation, 4,562,051 cubic yards; masonry, 573,494 cubic yards; giving a cost of $35,876,853.

Taking a mean of these as the probable cost, we have for a tunnel 60 feet wide at water-line and 116 feet high the sum of $33,241,923. In the final summary of expenses herewith given this sum is allowed. Those who consider a width of 70 feet as essential must add to the sum total there given $3,560,000.

THE POINTING BASIN.

The general direction of the valley of the Chiri-Chiri River makes an angle of some 40° with he tunnel, and to accomplish this change of direction no better plan has occurred to me than the pointing basin represented on Plate V.

The plan so nearly explains itself that a description is hardly necessary. It consists of an open cut, the ground-plan being very nearly in the shape of a sector of a circle, with a radius of 400 feet and chord of 290. It is excavated mainly in solid rock, and its sides have the same slope as other portions of the canal similarly situated.

At a height of 8 feet above normal water-surface a bench 10 feet wide extends around three sides to facilitate the operation of breasting-over passing vessels.

The northwestern side of the basin makes an angle of 5° with the tunnel, as a ship could make that change of direction while emerging from or entering the tunnel, and by constructing it in that way a considerable saving in excavation would be effected.

The operation of passing through such a basin is so simple as to require no description. The time occupied could not be more, and should be considerably less, than would be required for one lockage.

The estimates for this basin, which are simply the cost of the necessary excavation, are included in those for the western division of the canal.

SECTION V.

LOCKS.

The summit-level of the proposed canal being 143 feet above the plane of mean tide, the necessary locks to overcome this difference of level have been projected and estimates made of their probable cost. A portion of the difference on the Atlantic side is already overcome by the elevation of the surface of the Atrato at the point where the canal joins it.

Our line of levels gave 39 feet as the elevation of the banks of the Atrato at that point. According to the best of our observations and the testimony of the natives, the extreme variation in the level of the Atrato is 20 feet. This I regard as an extreme estimate, and it gives us 19 feet as the height of the surface of the river at its lowest stage. Nineteen feet from 143 feet leave 124 feet to be overcome by locks. For this purpose twelve, with a lift of 10.3 feet each, have been projected, and calculations made for them according to their locations, as shown on the profile.

The dimensions proposed are a length of 400 feet between miter-sills, and a clear inside width of 60 feet. The walls inside are to be perpendicular, but joined to the bottom by a circular arc, described with a radius of 10 feet. When the lock is situated in solid rock, a thickness of 3 feet of hydraulic concrete has been allowed for sides and bottom. When in earth, this thickness has been increased to 6 feet. When the walls rise above the surface, a thickness of 6 feet has been allowed for the top, and the outside is sloped off in steps so as to give at every point a thickness equal to .75 of the height above. The lift walls have a thickness of 15 feet, and ample chambers have been allowed.

For gates, machinery, and apparatus for filling and emptying the locks, I have allowed the same sums as given by Mr. Menocal in Commander Lull's report on Nicaragua. The items will be found in the synopsis.

The aggregate cost of these twelve locks, as estimated, is $2,511,552. This estimate does not include the cost of excavation, since that has been amply allowed for in the estimates for the excavation of the division in which they occur. The walls and bottoms have been estimated for as entirely in hydraulic concrete, the only dressed stone about the locks being 70 cubic yards in each for miter-sills.

On the Pacific side the entire difference of level of 143 feet must be overcome by locks. In fact, in order to enable ships of all classes to enter and leave the canal at all stages of the tide, some 6½ feet must be added to this, the rise and fall of spring-tides in Chiri-Chiri Bay being about 13 feet. We have, therefore, 149 feet difference to provide for, and estimates have been made for ten locks, with a lift of 14.9 feet each. The slope of the Pacific side is so abrupt, that there is room for no more than 10 locks "end on."

It is, of course, objectionable to place so many locks of heavy lift in a flight for many reasons, chief among which may be mentioned the danger of damage to the works from the enormous hydrostatic pressure in case of fissures in the rock; but there seems to be no way to avoid it. It is possible that some sort of a hydraulic lift might be resorted to; but the success of any such device appears very problematical. These locks are of the same general character and dimensions as those for the Atlantic side, with the exception of such changes as are called for by the increased lift. Their location is well shown on Plate V. The amount of material necessary for each has been carefully calculated, and their aggregate cost is estimated at $2,537,662. We have, then, as the aggregate cost of the locks required, according to these plans, the sum of $5,049,214.

SECTION VI.

CHARACTERISTICS OF THE STRATA REQUIRING EXCAVATION.

The importance of determining as accurately as possible the character of the soil through which the proposed cutting would have to be made was fully appreciated, and every effort was made to secure reliable data bearing on that question. The results of our efforts in this direction were not as satisfactory as I could wish, and our data is meagre.

The boring apparatus with which we were supplied proved entirely too heavy for our little force to operate satisfactorily, and, after a number of more or less successful trials, the necessity of putting all our strength on the line of survey compelled us to abandon its use entirely.

It can easily be seen that it was useless to employ an officer and four men all day in reaching a depth of 6 or 8 feet, when the character of the soil could be better ascertained to an equal depth by a simple inspection of the banks of the small streams crossing the line of survey. The latter method was therefore adopted, and some forty specimens showing the soil at depths varying from 5 to 20 feet were secured. These specimens, with several of rock, were sent to the Smithsonian Institution, with a request that they might be examined and a report made of their characteristics as bearing on the canal question; but the pressure of official duties on the part of the gentlemen connected with that Institution has thus far prevented their examination.

In the absence, therefore, of the opinion of an expert, I can only give the following general description, which may serve to convey some idea of the character of the soil along the line.

It will be seen that throughout the length of the line, if we except the swamps near the Atrato, the appearance of the soil is strikingly similar. Below the thin layer of vegetable mold we found everywhere a remarkably stiff, tenacious clay, blackish-red or blue in color, and generally free from any mixture of sand. It was this tenacious subsoil that so troubled us in boring. The first few feet were passed easily enough, but on striking the clay the united weight of four men would sometimes fail to force the screw to take, or, if it did take and advanced 8 or 10 inches, it was next to impossible with our appliances to withdraw it.

Cutting through this clay would, no doubt, be difficult and expensive. But, once cut, no better material for the construction of a canal could be desired. The ditch and embankments would, I feel confident, be practically impervious to water, while the great stiffness and tenacity of the clay would enable it to stand at a good slope, and to resist to a great extent the wearing of heavy rains and the wash at the water-surface of the canal.

Description of specimens of the soil along the line.

No.	How and whence obtained.	Depth at which found.	Characteristics.
		Feet.	
1	By boring on the bank of the Atrato near the Napipi	7	Dark clayey loam, free from sand.
2	......do	15	Plastic clay, blue and red mixed; appears to contain some very fine sand.
3	By boring near the banks of the Napipi about 5 miles from the Atrato, in low, flat country.	2	Fine sand, clay, and vegetable mold, dark reddish color.
4	......do	11	Plastic clay, stiff, smooth, and bluish.
5	......do	13	Very fine dark yellow sand, mixed with a little dark blue clay.
6	By boring near the Napipi 7 miles from Atrato. Low, flat country	3	Bright red, sandy clay.
7	......do	10	Smooth red clay, very stiff.
8	......do	14	Dark clay, red and brown mixed.

Description of specimens of the soil along the line—Continued.

No.	How and whence obtained.	Depth at which found.	Characteristics.
		Feet.	
9	.....do	15	Smooth blue clay, mixed with a little red.
10	By boring near the Napipi 9 miles from the Atrato, in low land, with hills in the vicinity.	7	Dark brown sandy clay.
11	.....do	12	Very fine dark yellow sand.
12	.....do	15	Dark bluish clay, with some fine yellow sand.
13	By boring near the Napipi 10 miles from the Atrato, on the side of a small hill.	1	Bright red sandy clay, very stiff and hard.
14	.....do	3	Stiff smooth clay, red and yellow.
15	.....do	7	Like 14, but stiffer.
16	By boring near the Napipi 12 miles from the Atrato, on the top of a low ridge.	6	Dark red sandy clay.
17	.....do	8	Fine yellowish sand, with some clay.
18	.....do	9	Coarse sandy clay.
19	By boring on the line of the proposed dam 20 miles from the Atrato	3	Dark bluish clay, very soft.
20	.....do	6	Like above, but stiffer.
21	.....do	7	Dark clay mixed with gravel, bed-rock below.
22	From the bottom of small stream 13 miles from the Atrato	10	Dark brown and red clay, with vegetable mold.
23	From the bottom of small stream 14 miles from the Atrato	12	Stiff smooth clay, blue and brown mixed.
24	From the bottom of stream about 15 miles from the Atrato	8	Same as 23.
25	From bottom of small stream near No. 24	5	Dark brown clay, smooth and stiff.
26	From bottom of "Catugado" 16 miles from the Atrato	12	Dark blue clay, smooth, stiff, and tenacious.
27	From bottom of small stream ½ mile to the westward of the Catugado	4	Smooth blue clay, indurated; looks almost like stone.
28	From bottom of stream 16 miles from the Atrato	8	Coarse sandy clay.
29	From bottom of small stream near 28	8	Smooth dark brown clay.
30	From bottom of stream 20 miles from the Atrato	10	Light blue clay, with very fine sand.
31	From the bottom of the Pidagado 18 miles from the Atrato	12	Dark brown sandy clay.
32	From the Pidagado 1 mile upstream from 31	15	Coarse sandy clay.
33	From bottom of small stream 17 miles from the Atrato	3	Smooth light blue clay, with very fine sand.
34	From banks of a stream 16½ miles from the Atrato. This stream has a sandy bottom.	6	Sand and clay.
35	From banks of Napipi about 7 miles, direct distance, from the Atrato	....	Coarse friable sandstone.
36	From the surface of the hills in the same vicinity as 35	....	Same as 35.
37	From the surface of the hills 8 miles from Atrato	....	Decomposed trap rock.
38	From the bank of the Napipi where the line runs very near the river, about 12 miles from the Atrato. The banks of the river in this vicinity are of this rock for more than half a mile and from 10 to 40 feet high.	....	Same as 37. This surface-rock is quite soft from exposure, but the bed-rock below is very hard.
39	From the cliffs on the right bank of the Doguado, about 4 miles above the junction of the Napipi.	......	Similar to 37.

In regard to the thickness of the overlying stratum of earth, we found this to depend, in any given part of the line, on the distance to the nearest hills. On the crests of the ridges, where the rock frequently cropped out, the thickness of earth averaged about 5 feet. In the intervening valleys it increased to 10 or 15 feet, and in the bottom-lands it would be 20 or more.

Above the junction of the Doguado the earth rarely exceeds 10 feet in depth. In the swampy lands near the Atrato no approximation to the thickness of the overlying earth has been attempted.

Wherever we found outcrops of the bed-rock, which were frequent on the river-banks, it presented uniform characteristics. It was invariably in a state of great disintegration, splitting up irregularly into small fragments, often so soft as to resemble clay. On the faces of high cliffs the rock is continually breaking away and tumbling down in large masses.

In some places I observed quite distinct traces of stratification, as though the rock were metamorphic, but generally it presented that irregular seamy appearance known as the distinguishing characteristic of a trappean formation.

When worn and polished by water, as in the river-beds, this rock appears very hard. In such cases it frequently is light-colored, resembling sandstone in appearance.

SECTION VII.

WATER-SUPPLY AND AQUEDUCT FROM THE RIO CUIA.

The essential question of the adequacy of the water-supply received our most careful attention.

Immediately upon arriving at the junction of the Napipi and Merindo Rivers, where headquarters were established on the 13th of February, careful observations of the volume of the Napipi immediately below the junction were commenced and continued daily, with but few interruptions, till the 27th of April. The manner in which these experiments were conducted will be found fully described in the report of Lieut. S. C. Paine, marked C in the Appendix.

The cross-section of the river was measured with all possible accuracy, all the measurements

being referred to a bench-mark on the left bank some 10 feet above the water at that period. From this bench-mark, by one setting of the instrument, the relative level of the water-surface could be ascertained to within $\frac{1}{100}$ of a foot.

The velocity of the current was measured by a delicate tachometer, made by Green, of New York, the constant of which had been determined by a careful experiment when it was in use in Nicaragua. A mean of several observations with this instrument was generally taken, and the area of the stream, multiplied by .84 of the velocity thus determined, gave the flow in cubic feet per minute.

Our observations extended through one of the driest seasons ever known in that section. By reference to the report on meteorology (C, Appendix), it will be seen that during fifty-four days only 2.2 inches of rain fell. The water-supply, as determined by us, may therefore be safely accepted as the minimum.

As it soon became evident that the Napipi alone would afford a totally insufficient supply, I took the earliest opportunity to run a line of levels to the Cuia River, for the purpose of obtaining data for estimating the cost of an aqueduct to feed the canal from that stream. Such a feeder had been proposed by Commander Selfridge, and under his direction a line of levels had been run in 1873 by Lieutenants Eaton and Sullivan, from the Cuia to the Napipi, at a point a few miles below the junction of the Merindo. This survey had demonstrated the practicability of feeding from the Cuia. It remained for us to make such further surveys as would afford data for estimating the character and cost of the necessary works.

Such a survey was accordingly made, mainly by Ensign Barroll, under circumstances of great difficulty. It is unnecessary to describe the survey in detail. It followed the lowest ground that could be found leading toward the Cuia, and at a point about midway between the two rivers joined the line of the survey of 1873, which gave the line of levels from river to river desired. But the survey of 1873 had followed the native trail, and was, therefore, for much of the way, on the highest ground rather than the lowest. All the time we could spare was therefore spent in running up the valleys on either side of the divide to obtain the lowest profile.

In projecting the line for the aqueduct, after the surveys had been plotted, it was found advisable to deviate considerably from the line of survey. But wherever these deviations occur the height has been assumed to be such as to require tunneling.

The works necessary for this aqueduct will be easily understood by the following description and an examination of the profile shown in Plate IV and the general map.

Immediately below the junction of the Salado with the Cuia a dam is to be thrown across the latter. It is to extend diagonally across the river from one rocky bluff to another. Its total length on the crest will be 770 feet and on the foundation 730 feet. Its total height will be 17 feet, and it will raise the waters of the Cuia 9 feet above dry-season stage, which will give a working head of 14 feet above the summit-level of the canal. The actual difference of level between the dry-season levels of the Napipi and Cuia is 30 feet, and the dam of 25 feet on the Napipi leaves a margin of 5 feet to add to the 9 feet to which the Cuia is to be raised.

This dam proposed for the Cuia is so similar to that for the Napipi, that a detailed description is unnecessary. Its cost is estimated at $71,299.

The cut for the aqueduct commences on the Salado about 4,000 feet from the dam. An open cut is continued for 2,900 feet, and then a tunnel 5,800 feet long carries the aqueduct under the main divide between the Cuia and Napipi and brings it out in the valley of a small tributary of the latter called the Cuita. In the valley of this tributary a second basin is to be formed by a short dam, situated as shown on the map, and for which estimates will be found in the synopsis under the head of Dam No. 2. To reach this basin from the tunnel just described a cut of 2,800 feet is necessary. To carry these waters to the main basin, we have then to pierce the divide between the Cuita and Merindo, for which purpose 3,020 feet of open cutting and 3,430 of tunnel are required. From these we have the following as the total length of the feeder-line requiring excavation:

	Feet.
Open cut	7,720
Tunnel	9,230
Total	16,950

Or about 3.2 miles. A fall of 14 feet in 3.2 miles gives a gradient of 4.3 feet to the mile, and the mean velocity of its current will be 4.28 feet per second, which would be excessive were it not for the fact that the cutting is entirely in rock.

For the best form and dimensions required to deliver 12,000,000 cubic feet daily with the given head I am indebted to Mr. Menocal. The cut is to be 6.5 feet wide at the bottom and the sides to slope 1 to 1 to a height of 3.5 feet, which will be the depth of water when that in the basin stands level with the crests of the dams. Under these circumstances the actual capacity of the aqueduct will be 150 cubic feet per second, or 12,960,000 cubic feet daily. Where tunneling is required, the form of transverse section consists of the trapezoidal section just described, surmounted by a semi-circular arch. This gives a total height of 10.25 feet by a width of water-surface of 13.5. In a tunnel of such small dimensions it has been assumed that the rock will sustain itself without lining.

Mr. Menocal estimates the probable loss from evaporation and filtration in this aqueduct at 75,000 cubic feet daily.

The cost of this aqueduct may be summed up as follows:

Excavation, open cut	$134, 139
Excavation, tunnel	291, 528
Dam No. 2, across the Cuita	51, 760
Dam No. 3, across the Cuia	71, 299
Total	$548, 726

I will now present, in the form of a table, the result of our observations and calculations as to water-supply.

The first column of the table shows the date; the second, the *observed* flow of the Napipi; the third, the *estimated* delivery of the feeder; the fourth, the two added together, as the total daily supply.

The daily delivery of the aqueduct was thus estimated. The few cross-sections of the *Cuia* that we were able to obtain showed it to be about equal to the Napipi in volume. Whenever, therefore, the flow of the Napipi exceeds 12,000,000 cubic feet daily, the aqueduct is supposed to be bringing its full capacity from the Cuia. Whenever the Napipi falls below 12,000,000, the aqueduct is supposed to bring the whole flow of the Cuia, which is assumed as equal to that of the Napipi.*

Table showing the minimum water-supply. From observations during the months of February, March, and April, 1875.

(Lieut. S. C. Paine, U. S. N., observer.)

Date.	Observed flow of Napipi.	Estimated delivery of aqueduct.	Total daily supply.	Date.	Observed flow of Napipi.	Estimated delivery of aqueduct.	Total daily supply.
Feb. 13	12, 143, 050	12, 000, 000	24, 143, 050	Mar. 29	7, 778, 120	7, 778, 120	15, 570, 240
14	13, 866, 410	12, 000, 000	25, 866, 410	30	7, 785, 120	7, 785, 120	15, 570, 240
15	12, 945, 410	12, 000, 000	24, 945, 410	31	7, 785, 120	7, 785, 120	15, 570, 240
16	14, 267, 930	12, 000, 000	26, 267, 930	Apr. 1	7, 785, 120	7, 785, 120	15, 570, 240
17	12, 007, 010	12, 000, 000	24, 007, 010	2	7, 776, 440	7, 776, 440	15, 552, 880
18	11, 118, 940	11, 118, 940	22, 237, 880	3	7, 344, 240	7, 344, 240	14, 688, 480
19	12, 882, 050	12, 000, 000	24, 882, 050	4	7, 344, 240	7, 344, 240	14, 688, 480
20	11, 007, 380	11, 007, 380	22, 014, 770	5	7, 344, 240	7, 344, 240	14, 688, 480
21	11, 007, 380	11, 007, 380	22, 014, 770	6	7, 200, 000	7, 200, 000	14, 400, 000
22	10, 848, 460	10, 848, 460	21, 696, 520	7	6, 552, 000	6, 552, 000	13, 104, 000
23	10, 890, 620	10, 890, 620	21, 781, 240	8	6, 192, 000	6, 192, 000	12, 384, 000
24	10, 895, 830	10, 895, 830	21, 791, 660	9	5, 814, 960	5, 814, 960	11, 629, 920
25	10, 846, 820	10, 846, 820	21, 693, 640	10	8, 160, 000	8, 160, 000	16, 320, 000
26	10, 327, 940	10, 327, 940	20, 655, 880	11	267, 960, 960	12, 000, 000	279, 960, 960
27	9, 883, 150	9, 883, 150	19, 766, 300	12	28, 067, 480	12, 000, 000	40, 067, 480
28	9, 883, 150	9, 883, 150	19, 766, 300	13	26, 160, 000	12, 000, 000	38, 160, 000
Mar. 1	8, 947, 200	8, 947, 200	17, 894, 400	14	57, 757, 680	12, 000, 000	69, 757, 680
2	8, 916, 720	8, 916, 720	17, 833, 444	15	78, 960, 000	12, 000, 000	90, 960, 000
3	8, 885, 420	8, 885, 420	17, 770, 840	16	98, 967, 890	12, 000, 000	110, 967, 890
4	8, 411, 760	8, 411, 760	16, 823, 520	17	36, 319, 680	12, 000, 000	48, 319, 680
5	8, 411, 760	8, 411, 760	16, 823, 520	18	52, 560, 000	12, 000, 000	64, 560, 000
6	8, 382, 240	8, 382, 240	16, 764, 480	19	67, 852, 800	12, 000, 000	79, 852, 800
7	8, 382, 240	8, 382, 240	16, 764, 480	20	20, 160, 000	12, 000, 000	32, 160, 000
8	8, 882, 240	8, 382, 240	16, 764, 480	21	12, 263, 040	12, 000, 000	24, 263, 040
9	8, 382, 240	8, 382, 240	16, 764, 480	22	11, 520, 000	11, 520, 000	23, 040, 000
10	8, 382, 240	8, 382, 240	16, 764, 480	23	10, 787, 040	10, 787, 040	21, 574, 080
No observations from 10th to 26th.				24	22, 275, 360	12, 000, 000	34, 275, 360
26	8, 681, 280	8, 681, 280	17, 360, 560	25	18, 960, 000	12, 000, 000	30, 960, 000
27	8, 217, 840	8, 217, 840	16, 435, 680	26	15, 600, 000	12, 000, 000	27, 600, 000
28	7, 785, 120	7, 785, 120	15, 570, 240	27	12, 199, 680	12, 000, 000	24, 199, 680

* It will be observed that in these calculations the Cuia only is taken into account. The plan for the feeder proposes to utilize the flow of the Cuita also. The flow of this may safely be assumed as never less than 500,000 cubic feet daily, which amount must be amply sufficient to cover all losses and leave a wide margin.

The above table shows, as fully as need be, the water-supply that can be counted upon with certainty during the driest seasons. In addition, there is the reserve in the three basins, that can be drawn upon when required. This reserve I estimate roughly (for I have no data for an exact statement) at 150,000,000 cubic feet.

In case of necessity, there remains as a final resort, the river Opogado, next to the northward of the Napipi. No survey has ever been made between these two rivers, but from general knowledge of the topography of the locality, and the results of our survey to the Cuia, I should say that it is altogether probable that an aqueduct could be constructed from the Opogado at a cost not exceeding $1,000,000, and that 12,000,000 cubic feet daily at the lowest estimate could be counted upon. I give these merely as suppositions. They must be taken only for what they may be worth.

The question of water-supply, without recourse to the Opogado at least, I consider very fairly settled. The question of the adequacy of this supply I have not been able to answer with any satisfaction to myself. Not only is the amount of shipping that would seek the canal altogether uncertain, but, granted that we knew with reasonable accuracy the tonnage to be accommodated, the amount of water it would require would depend very much on the shape in which it should present itself.

The projected locks will accommodate with ease a ship of 5,000 tons, or two of 2,000 each, or three or four small craft. If, therefore, the shipping should present itself in such a way that the full capacity of the locks could be utilized, it would require to accommodate the 3,000,000 tons that it is supposed would pass through the canal yearly* an average of only about 2,500,000 cubic feet of water daily. Losses from all causes are not for the present considered. If, on the other hand, the vessels should be mainly of small size, and should present themselves for passage singly, the same tonnage would require three or four times that amount of water.

If we may assume that on an average 1,000 tons of shipping will pass through at each lockage, we may calculate as follows for double the amount of tonnage just mentioned, that is to say, for 6,000,000 tons yearly.

It requires no argument to show that in a canal fed exclusively from the summit, and without devices for saving water at the flights of locks, economy in the expenditure of water requires that ships should pass in either direction in trains. Such an arrangement would be convenient and, perhaps, necessary on other considerations, and I will proceed on the supposition that an arrangement to pass eight ships of 1,000 tons each (that being assumed as the average amount, whether in one or more vessels) in each direction daily is in operation.

The first ship passing to the westward would find the Atlantic locks empty, they having been so left by the last ship passing eastward, and at each of these locks she would require one lockful of water, which must, of course, be drawn from the summit. On passing into the Pacific locks, she would find them all full, and from the summit-lock she would send back into the summit-level a quantity of water equal to her displacement, and descend to the Pacific without further draft on the supply Her successors passing in the same direction would find these conditions reversed. They would find the Atlantic locks full, and would ascend to the summit with the expenditure of one lockful of water each. They would find the Pacific locks empty, and would descend with one lockful each, less displacement. The eight ships passing to the westward would, therefore, have expended 19 Atlantic lockfuls plus 7 Pacific lockfuls, less their aggregate displacement. These having passed, the transit of those bound eastward would begin. The first of these would find the Pacific locks empty, and would require each one lockful. She would find the Atlantic locks full and would send back a quantity equal to her displacement, and descend without draft on the supply. Her successors, finding these conditions reversed, would ascend with one lockful each and descend with one lockful each, less displacement.

This may be tabulated and rendered clearer as follows, letting l equal the quantity required

* See page 93, Report of Commander Selfridge.

to fill an Atlantic lock, l' the quantity required to fill a Pacific lock, and d the average displacement:

Direction in which bound.	Atlantic.	Pacific.
First vessel passing westward	$12l$	$0-d$
Seven following successively	$7l$	$7l'-7d$
Expenditure for eight vessels westward	$19l$	$7l'-8d$
First vessel passing eastward	$0-d$	$10l'$
Seven following successively	$7l-7d$	$7l'$
Expenditure for eight vessels eastward	$7l-8d$	$17l'$
Daily expenditure for eight vessels each way	$26l-8d$	$24l'-8d$

It becomes evident, from an inspection of this table, that economy in expenditure of water would result from passing as many vessels as possible in the same direction consecutively. It would be advantageous, then, as far as water is concerned, to set apart alternate days for passing in either direction. On this supposition the expenditure for sixteen ships will become as follows:

Direction in which bound.	Atlantic.	Pacific.
First vessel passing westward	$12l$	$0-d$
Fifteen following successively	$15l$	$15l'-15d$
Expenditure for sixteen vessels westward	$27l$	$15l'-16d$
First vessel passing eastward	$0-d$	$10l'$
Fifteen following successively	$15l-15d$	$15l'$
Expenditure for sixteen vessels eastward	$15l-16d$	$25l'$
Daily average for sixteen vessels	$21l-8d$	$20l'-8d$

The expression for the expenditure for sixteen vessels either way on alternate days becomes $21l+20l'-16d$.

In this expression, the value of $l=247{,}200$ cubic feet. The value of $l'=357{,}600$ cubic feet. The value of d is supposed to average 32,260 cubic feet. Substituting these values, we have $5{,}191{,}200+7{,}152{,}000-516{,}160=11{,}827{,}040$ cubic feet as the daily expenditure of water for 6,000,000 tons of shipping yearly.

The above calculations are founded on the supposition that the shipping seeking passage should present itself in equal portions on each side daily throughout the year. No such favorable conditions could obtain in actual practice; and it would also be an essential factor in any reliable estimate of the adequacy of the water-supply to know the distribution of the shipping according to months. In all months of the year, except March, April, August, and, perhaps, September, the supply would be ample for all possible demands. It would therefore be essential to know whether the press of business would be likely to occur during these months, or whether the monthly average would be practically the same the year round.

And now there remains to be considered a still more uncertain element in our calculations—that of *waste*, from all causes. The evaporation may be closely approximated from the experiments of Commander Selfridge,* and in that moist climate it is not of great moment. Five hundred thousand cubic feet daily would be a liberal allowance for waste from this cause. But I am totally at a loss to estimate the waste from *leakage* and *filtration*. With the canal mainly in rock and impervious clays, and with all locks, culverts, and dams of solid hydraulic concrete, the loss from these causes should be reduced to a minimum. But, having shown the supply that may be relied upon, and the probable demand for passing ships, I will leave the question as to whether the margin is sufficient to cover probable losses to those more competent to decide it.

It should not, however, it seems to me, be forgotten that, as pointed out by Commander Lull, in a canal with as many deep cuts as has the one in question, more water would be likely to filter *into* the canal than *out* of it.

*These gave a mean of 0.20 of an inch in 24 hours. The experiments of Captain Shufeldt at Tehauntepec agree closely with this, showing 0.19 of an inch daily. (See page 87, Report of Commander Selfridge.)

SECTION VIII.

METEOROLOGY AND CLIMATE.

It is unnecessary, for the purposes of this report, to enter into any extended discussion of the questions arising under these heads.

During our entire stay meteorological observations were conducted, with such instruments as we had at hand, under the supervision of Lieutenant Paine, and he has prepared a report (see Appendix C and Plate IX) in which the results are presented. No attempt has been made to discuss the data acquired. It is presented simply as obtained, in the hope that it may be found interesting and perhaps valuable to specialists in that science, as meteorological data concerning that region must be much wanted.

The observations of a thermometer exposed to the sun may be of interest as showing the heat to which laborers would be exposed. The observations gave a mean of 97° Fahr. as the midday temperature; the minimum being 82° and the maximum 114°. It should be stated, however, that 114° was the limit to the graduation of our thermometer, and on one or two occasions it appeared that the mercury would have gone higher if permitted. The prevailing winds at the junction of the Napipi and Merindo, during our entire stay, were from the southward; exactly opposite to the direction from which we had expected them. On the Atrato they prevailed, as would naturally be supposed, from the northward. At the junction, at a height of 150 feet above the sea-level, we had daily a refreshing breeze from the southward, springing up about 10 a. m. and frequently lasting till sundown. I have never known a gale during the three seasons I have spent in that vicinity. In fact, I cannot now recall an instance of a violent squall even.

During our stay, from the 13th February to 28th April, a total of 10.42 inches of rain fell, distributed as follows:

	Inches.		Inches.
Feb. 15	0.04	Apr. 19	0.48
23	0.66	21	0.15
Mar. 10	0.51	23	0.34
19	0.04	24	0.15
20	0.31	25	0.44
22	0.71	26	0.04
Apr. 9	0.25	27	0.16
11	1.84	28	0.20
14	0.61		
16	3.16	Total	10.42
18	0.56		

It will be seen that during 74 days during which observations were taken, rain fell on 19 days, and that up to the 9th of April (which date may be taken as marking the commencement of the rainy season in this case) rain fell on 6 days only out of 55. Of the entire observed rainfall, 8.18 inches fell during the last 20 days—by far the greater part of this fell during the night. In general no such period of drought occurs, and the natives told me that in the year preceding there was no distinctly marked dry season at all.

As a rule, however, two well-marked dry seasons occur, with corresponding periods of rain. January, February, and March are the months which constitute the driest and pleasantest season. In April the rains commence, and in May and June they are very heavy. In July a second dry season begins to set in, and August and September are generally pleasant. In October rains again commence, and in November and December they are at their heaviest.

Briefly, then, five months of the year may be called dry and seven wet, while occasional years may be expected with little or no dry season at all.

CLIMATE.

Regarded from a sanitary point of view, it would appear that this climate is quite as healthy as any within the tropics. A discussion of the question will be found in the report of Assistant Surgeon Norfleet, marked D in the Appendix. From that it will be seen that up to the time work

was begun in the swamps the health of the members of the expedition was uniformly good. The number of "sick days" in his report seems large, but this is accounted for by the fact that one man was disabled during almost the whole of our stay by a cutaneous disease that could not fairly be laid to the charge of the climate, while another placed himself *hors du combat* for a considerable period by gratifying his craving for liquor with raw alcohol supplied for a different purpose.

With the exception of a strip some five or six miles wide near the Atrato, I consider that the projected line lies through a healthy region. In the more elevated portions of the route, as above the junction of the Merindo, the climate during the dry months is simply delightful. Those members of the expedition whose labors were confined to that section escaped all serious sickness.

The experience of all the expeditions goes to show that, with good food, good shelter at night, flannel clothes, and proper attention to cleanliness, men can endure great labor in that country. It was only when the exigencies of the survey prevented the fulfillment of those conditions that sickness resulted. I do not see why, during the construction of a canal, they may not all be fulfilled much more effectually than our circumstances permitted.

Attention to these details would be of paramount importance anywhere within the tropics. The laborers must be well clothed, well fed, and well sheltered in quarters situated with special reference to sanitary conditions rather than convenience in getting to and from work. Commodious hospitals must be provided, the little ailments promptly treated, and time for rest and recuperation after illness allowed; opportunity to indulge in spirituous liquors to excess must not be allowed, and, in a word, the laborers must be treated as *men* worth caring for; otherwise the opening of a canal on any one of the projected lines will require as many thousands of lives as millions of dollars.

SECTION IX.

MATERIALS FOR CONSTRUCTION.

As the projected canal-line lies through an almost unbroken primeval wilderness, and as our observations extended over a very limited area, our knowledge of its capabilities of affording the requisite materials for the construction of the canal and its appurtenances is very imperfect. We know, however, that the entire country, with the exception of the swamps, is well covered with heavy timber of many varieties, some of which are of great beauty and value. I obtained some thirty specimens of the finer sorts of wood, a list and description of which will be found in the Appendix, marked H.

So far as timber is concerned, there can be no doubt that an abundance of every needful variety would be found immediately at hand.

As regards the existence of the necessary stone, clay, sand, &c., in the absence of more definite information, in addition to what has been already given in the description of the strata requiring excavation, I can do no better than quote from the report of the geologist who accompanied Lieutenant (now Brigadier-General) Michler on his survey of the Truando in 1857.

The Truando is a tributary of the Atrato, similar to the Napipi, and about 80 miles to the northward. While it is by no means certain that the geological structure of the two sections is identical, I see no reason for supposing that it should be very different. The geologist of the Truando expedition says:

In regard to the probable degree of development, and the respective extent of each of the strata constituting the Isthmus, we are not able to go beyond certain conjectures, especially in respect to its western portion.

So far as sedimentary strata are concerned, a proposed cutting through will meet with no serious obstacle, whilst at the same time this section will furnish choice material for building purposes. Calcareous rock may be expected almost to a certainty within the bounds of the Tertiary and secondary formations, whilst the Quaternary and alluvium in general will readily furnish plastic clay and clean drift-sand. Heavy rock for foundations and cyclopean work generally will be furnished by the Trappean series. Material of this kind may be found of every degree of hardness and gravity within the limits of the Sierra de los Saltos; that is, from the head to the foot of the Truando Falls. [It appears to be the main bed-rock all along the Napipi line.—F. C.] * * * The schistose nature of this rock would greatly assist not only in blasting, but even in laboring with the pickax.*

As already stated, the mass of the soil along the line is a stiff, tenacious, impervious clay, generally free from sand, and admirably adapted to embankments. On the Pidagado and in other

*See page 172, Report of Lieutenant Michler.

places we found a very smooth blue clay that would make most excellent puddle. Near the mouth of the Merindo there are banks of a fine whitish clay, used by the natives in the manufacture of pipes for smoking tobacco and in rude attempts at pottery.

SECTION X.

HARBORS.

I was not directed in my instructions to seek for any additional data bearing on the question of harbors, and have none to present. I consider them merely to arrive at an estimate of the cost of such improvements as they may require, as an item in the sum total required for a canal by this route.

It is evident from an examination of the chart of the Gulf of Urabá, given in the report of Commander Selfridge, that it is as fine and commodious a harbor as could be desired. As a harbor, it requires no outlay, but a channel must be kept open through the bar at the mouth of the Atrato, if that river is to be made use of as is proposed in the canal scheme now under consideration.

The question of the practicability of preserving an open channel through this bar by the construction of parallel piers or jetties to confine the current does not need to be discussed here. If any doubts have heretofore existed as to its practicability, they must now be set at rest by the success that has thus far attended a similar operation at the mouth of the Mississippi, where the conditions are altogether less favorable than at the mouth of the Atrato.

To arrive at an approximation of the probable cost of this work, I have estimated for parallel piers according to a plan suggested by Mr. Menocal. Each pier is to consist of two rows of long sheet piles 30 feet apart; the space thus inclosed is to contain two more rows of piles 5 feet apart in the direction of the length of the wall and 10 feet apart in the direction of its width; these are to be all firmly bound together by longitudinal and transverse stringers, and the whole space filled with clay and fascines. Walls of this character on either side of the proposed channel would, it is believed, result in the formation of permanent banks. They would probably require extension from time to time.

A dam of similar construction would be necessary to close up such mouths of the delta as might be necessary to give sufficient scouring strength to the current.

For all this work, and the required dredging, estimates will be found in the synopsis. The estimates are, of necessity, very rough. The cost amounts in round numbers to $818,000.

The reconnaissance of Commander Lull and Lieutenant Merrill shows so conclusively that the Atrato River requires no improvement from the bar to the Napipi, that it is unnecessary to do more than allude to the subject here. It may be well to state, however, that a line of soundings across the river, made by Lieutenant Eaton opposite the point where the canal-line leaves the river, showed 30 feet in the channel, although the river was then very low.

CHIRI-CHIRI BAY.

The proposed terminus on the Pacific side is merely an indentation in the coast open to all winds from northwest to south-southwest. The hydrographic survey made in 1873 by Lieutenant-Commander Jewell and Lieutenant Norris, of the U. S. S. Tuscarora, Commander Geo. E Belknap, commanding, affords the data for arriving at an estimate of the cost of the necessary works to protect the entrance to the canal.

The bottom of the bay is mainly sand, and affords good holding-ground. Violent gales are of extremely rare occurrence in that locality, and but little trouble would be likely to be experienced for the want of a more land-locked harbor at this terminus. A very heavy surf rolls in on the beach at all times, rendering landing a hazardous operation occasionally. To protect the entrance of the canal from this surf, and to afford a refuge for disabled vessels, works of considerable magnitude would be required. Those that have been proposed for this purpose will be readily understood by reference to Plate V. The head of the long pier lies in eight fathoms of water, and its length is 3,620 feet. The head of the short pier lies in five fathoms, and its length is 1,500 feet.

The distance between the pier-heads is 600 feet. The tops of the piers are to be 10 feet above high water. On the inside, they slope off at a grade of 1½ to 1. On the outside, the slope is curved, the dotted lines on the plan marking, approximately, the bottom width of the structures. These piers inclose a space beyond the 26-foot line 1,700 feet long by an average of 500 wide, giving an area of about 18 acres. The area beyond low-water mark has an average width of 1,000 by a length of 2,000, inclosing an area of about 50 acres. The construction of the piers here proposed would require an enormous mass of material and involve correspondingly heavy expense. A different plan, involving much less expensive piers, might, of course be adopted; but if the piers were not extended into deep water, it is quite likely that the cost of the dredging that would be required to form the basin would be greater than the saving on the piers. For it would be a matter of no little difficulty to secure still water in the basin; and dredging where there is any swell is well known to be difficult and expensive.

However, it is, of course, understood that this is not presented as anything more than a *possible* solution of the harbor question, and my only idea has been to arrive at such estimates as would be likely to cover the cost of whatever plan might be adopted.

I have calculated, somewhat roughly, the contents of the piers proposed as shown on the plate, and find the amount to be 861,200 cubic yards. This material will be taken close at hand, from the excavations of the Pacific slope and the western end of the tunnel. The sums that have been allowed for the excavation of this material are supposed to include the cost of dumping it at the most convenient points. In allowing, then, for the cost of the breakwaters, we must consider what additional sum will cover the extra expense of dumping it exactly where wanted to give the required form to the piers. For this purpose, $2.50 per cubic yard is supposed to be sufficient. At this price the cost of the breakwaters becomes $2,163,000.

A light-house would, of course, be required at each terminus, and for their construction $30,000 each has been allowed.

SECTION XI.

SYNOPSIS OF ESTIMATES.

Lengths and limits of divisions.

	Miles.
Eastern division, from Atrato to crossing	20.63
Middle division, from crossing to tunnel	4.81
Tunnel division	3.50
Western division, from tunnel to Pacific	1.30
Total length of canal	30.24

ESTIMATED COST OF EASTERN DIVISION.

9,049,719 cubic yards excavation in earth, at 35 cents	$3,167,402
4,012,944 cubic yards excavation in rock, at $1.25	5,016,180
1,337,648 cubic yards excavation in rock, at $1.50	2,006,472
3,082,523 cubic yards embankment, at 10 cents	308,252
	10,498,306

Lift-locks—Eastern Division.

Lock No. 1:

8,347 cubic yards hydraulic concrete, at $7.75	$64,689
70 cubic yards dressed stone in miter sills, at $18	1,260
Cast-iron pipes	31,968
Man-holes	7,929
Laying iron pipes	7,608
Valves, gates, and machinery	30,000
	143,454

Lock No. 2:

8,347 cubic yards hydraulic concrete, at $7.75	$64,689
Other items as in lock No. 1	78,765
	143,454

Lock No. 3:

18,978 cubic yards hydraulic concrete, at $7.75	$147,079
Other items as in lock No. 1	78,765
	225,844

Lock No. 4:

17,445 cubic yards hydraulic concrete, at $7.75	$135,199
Other items as in lock No. 1	78,765
	213,964

Lock No. 5:

21,380 cubic yards hydraulic concrete, at $7.75	$165,695
Other items as in lock No. 1	78,765
	244,460

Lock No. 6:

26,065 cubic yards hydraulic concrete, at $7.75	$202,004
Other items as in lock No. 1	78,765
	300,769

Lock No. 7:

8,347 cubic yards hydraulic concrete, at $7.75	$64,689
Other items	78,765
	143,454

Lock No. 8:

8,296 cubic yards hydraulic concrete, at $7.75	$64,294
Other items	78,765
	143,059

Lock No. 9:

24,728 cubic yards hydraulic concrete, at $7.75	$191,642
Other items	78,765
	270,407

Lock No. 10:

41,007 cubic yards hydraulic concrete, at $7.75	$317,804
Other items	78,765
	396,569

Lock No. 11:

8,296 cubic yards hydraulic concrete, at $7.75	$64,294
Other items	78,765
	143,059

Lock No. 12:

8,296 cubic yards hydraulic concrete, at $7.75	$64,294
Other items	78,765
	143,059

Total cost of locks, Eastern Division	$2,511,552

NOTE.—The cost of *excavation* for the locks is allowed for in the estimates for the division in which they occur.

Culverts—Eastern Division.

***Culvert No.* 1:**	
17,200 cubic yards excavation in earth, at 35 cents	$6,020
39,200 cubic yards hydraulic concrete, at $8	313,600
	319,620
***Culvert No.* 2:**	
30,070 cubic yards excavation in earth, at 35 cents	$10,524
51,280 cubic yards hydraulic concrete, at $8	410,240
	420,764
***Culvert No.* 3:**	
14,050 cubic yards excavation in earth, at 35 cents	$4,917
27,090 cubic yards hydraulic concrete, at $8	216,720
	221,637
***Culvert No.* 4:**	
8,360 cubic yards excavation in earth, at 35 cents	$2,926
40,030 cubic yards hydraulic concrete, at $8	320,024
	322,950
***Culvert No.* 5:**	
15,330 cubic yards excavation in earth, at 35 cents	$5,365
25,410 cubic yards hydraulic concrete, at $8	203,280
	208,645
***Culvert No.* 6:**	
16,160 cubic yards excavation in earth, at 35 cents	$5,656
16,740 cubic yards hydraulic concrete, at $8	133,920
	139,576
***Culvert No.* 7:**	
33,480 cubic yards excavation in earth, at 35 cents	$11,718
28,100 cubic yards hydraulic concrete, at $8	224,800
	236,518
***Culvert No.* 8:**	
27,070 cubic yards excavation in earth, at 35 cents	$9,474
25,150 cubic yards hydraulic concrete, at $8	201,200
	210,674
***Culvert No.* 9:**	
30,700 cubic yards excavation in earth, at 35 cents	$10,745
25,130 cubic yards hydraulic concrete, at $8	201,040
	211,785
***Culvert No.* 10:**	
27,400 cubic yards excavation in earth, at 35 cents	$9,590
26,430 cubic yards hydraulic concrete, at $8	207,440
	217,030

Culvert No. 11:

12,000 cubic yards excavation in earth, at 35 cents	$4,200
11,590 cubic yards hydraulic concrete, at $8	92,720
	96,920

Culvert No. 12:

40,040 cubic yards excavation in earth, at 35 cents	$14,014
48,920 cubic yards hydraulic concrete at $8	391,360
	405,374
Total cost of culverts, Eastern Division	$3,011,493

Side drains.

740,500 cubic yards excavation in earth, at 30 cents	$222,150
478,500 cubic yards excavation in rock, at $1.25	598,125
	$820,275

Diversion of the Napipi River.

At curve 5—950 *feet:*

24,480 cubic yards excavation in earth, at 30 cents	$7,344
222,656 cubic yards excavation in rock, at $1.25	278,320
	285,664

Near Braso Muriel—1,650 *feet:*

49,867 cubic yards excavation in earth, at 30 cents	14,960

At curve 6—1,250 *feet:*

35,007 cubic yards excavation in earth, at 30 cents	10,502
27,404 cubic yards excavation in rock, at $1.25	34,255
12,350 cubic yards hydraulic concrete, at $8	98,800
	143,557

At straight 10—300 *feet:*

28,322 cubic yards excavation in earth, at 30 cents	8,496
14,880 cubic yards hydraulic concrete, at $8	119,040
	127 536
Total cost of diversion of the Napipi	$571,717

Siding at curve 5:

7,440 cubic yards hydraulic concrete, at $8	$59,520

The cost of excavation for this siding is allowed in the estimate for the division.

Recapitulation of Eastern Division.

Excavation and embankment	$10,498,306
Locks	2,511,552
Culverts	3,011,493
Drains	820,275
Diversion of the Napipi	571,717
Siding	59,520
Grubbing and clearing	149,800
Total cost of Eastern Division	$17,642,663

MIDDLE DIVISION.

1,082,559 cubic yards excavation in earth, at 35 cents	$378,895
4,827,800 cubic yards excavation in rock, at $1.25	6,034,750
4,827,800 cubic yards excavation in rock, at $1.50	7,241,700
	13,655,345

Side drains:

180,105 cubic yards excavation in earth, at 30 cents	$54,031
833,746 cubic yards excavation in rock, at $1.25	1,042,182
277,915 cubic yards excavation in rock, at $1.50	466,862
	1,563,075

Diversion of Doguado River:

98,913 cubic yards excavation in earth, at 30 cents	$29,674
585,940 cubic yards excavation in rock, at $1.25	615,237
198,620 cubic yards excavation in rock, at $1.50	297,930
1,587 cubic yards stone wall at basin, at $4	6,348
	949,189

Basin:

1,404,179 cubic yards excavation in earth, at 35 cents	$491,463
1,140,712 cubic yards excavation in rock, at $1.25	1,425,890
	1,917,353

Dam No. 1 (across the Napipi):

188,855 cubic yards excavation in earth, at 35 cents	$66,099
185,625 cubic yards excavation in rock, at $1.25	232,031
9,709 cubic yards coursed masonry, at $15	145,635
5,920 cubic yards concrete in foundation, at $7	41,440
12,279 cubic yards concrete in hearting, at $8	98,232
200 cubic yards dry-stone wall, at $4	800
9,200 cubic yards stone filling under apron, at 50 cents	4,600
79,000 cubic feet of timber in apron, at 30 cents	23,700
880 piles, at $4	3,520
	616,057

Recapitulation of Middle Division.

Excavation and embankment (including basin)	$15,572,698
Drains	1,563,075
Diversion of Doguado	949,189
Dam No. 1	616,057
Grubbing and clearing	34,900
Total cost of Middle Division	$18,735,919

TUNNEL DIVISION. (See Plate VI.)

Plan A—70 feet wide; 27 feet water;* 86 feet high above water.

I. For unsound rock with elliptical arch springing from water-surface:

5,102,862 cubic yards excavation in rock, at $5.35	$27,300,312
682,993 cubic yards masonry, at $20	13,659,960
	40,960,272

*These are the minimum depths of water. With the water in the summit-level at its normal stage, they would be increased by 2 feet.

II. For sound rock with segmental arch of 120°; sides battered 1 to 20; spring of arch 60 feet above water:

5,279,843 cubic yards excavation in earth, at $5.35	$28,246,160
203,498 cubic yards masonry, at $20	4,069,960
	32,316,120

Plan B—60 feet wide; 30 feet water;* 86 feet high above water.

I. For unsound rock, as above:

4,562,051 cubic yards excavation in rock, at $5.35	$24,406,973
573,494 cubic yards masonry, at $20	11,469,880
	35,876,853

II. For sound rock, as above:

4,915,397 cubic yards excavation in rock, at $5.35	$26,297,374
199,181 cubic yards masonry, at $20	3,983,620
	30,280,994

Shafts:

16,300 cubic yards excavation in rock, at $10	$163,000

WESTERN DIVISION.

178,002 cubic yards excavation in earth, at 35 cents	$62,300
585,604 cubic yards excavation in rock, at $1.25	732,005
860,063 cubic yards excavation in rock, at $1.50	1,290,094
53,900 cubic yards excavation in earth below water, at 50 cents	26,950
103,009 cubic yards excavation in rock below water, at $5	515,045
	2,626,394

Ten locks (Nos. 13 to 22, inclusive):

225,808 cubic yards hydraulic concrete, at $7.75	$1,750,012
Other items as in lock No. 1	787,650
	2,537,662

Culvert No. 13:

2,489 cubic yards hydraulic concrete, at $7.75	$19,912

Side drains:

56,866 cubic yards excavation in earth, at 30 cents	$17,060
39,634 cubic yards excavation in rock, at $1.25	49,542
	66,602

Diversion of Chiri-Chiri River:

17,787 cubic yards excavation in rock, at $1.25	$89,733

Recapitulation of Western Division.

Excavation and embankment	$2,626,394
Locks	2,537,662
Culvert	19,912
Drains	66,602
Diversion of Chiri-Chiri River	89,733
Grubbing and clearing	7,200
Total cost of Western Division	$5,347,503

AQUEDUCT FROM THE RIO CUIA.

107,311 cubic yards excavation in rock, at $1.25	$134,139
36,441 cubic yards tunneling, at $8	291,528
	425,667

Dam No. 2 (across brook Cuita):

2,623 cubic yards excavation in earth, at 35 cents	$918
2,109 cubic yards hydraulic concrete, at $8	16,872
1,598 cubic yards masonry, at $15	23,970
10,000 cubic yards riprap for apron, at $1	10,000
	51,760

Dam No. 3 (across Rio Cuia):

2,736 cubic yards excavation in earth, at 35 cents	$957
2,000 cubic yards excavation in rock, at $1.25	2,500
1,598 cubic yards masonry, at $15	32,280
3,149 cubic yards hydraulic concrete, at $8	25,192
10,370 cubic yards riprap for apron, at $1	10,370
	71,299
Total cost of aqueduct	$548,726

BREAKWATERS AT CHIRI-CHIRI BAY.

861,200 cubic yards stone, at $2.50	$2,163,000

IMPROVEMENT OF THE URABÁ MOUTH OF THE ATRATO.

880 cubic yards dredging, at 50 cents	$440,000
17,978 piles, at $5	89,900
176,000 cubic yards filling, at $1	176,000
38,600 cubic feet timber, at 30 cents	11,880
Obstruction of other mouths of delta	100,000
	$817,780

FINAL RECAPITULATION.

Excavation and embankment	$28,697,398
Tunnel	33,241,923
Locks	5,049,214
Culverts	3,031,405
Side drains	2,449,953
Diversion of rivers	1,670,159
Dam for crossing Napipi	616,057
Aqueduct	548,726
Breakwaters at Chiri-Chiri	2,163,000
Improvement mouth of Atrato	817,780
Light-houses	60,000
Grubbing and clearing	191,900
	78,557,515
Add 25 per cent. for contingencies	19,636,879
Total estimated cost of canal and appurtenances	98,194,394

SECTION XII.

LOCAL ADVANTAGES AND DISADVANTAGES: GENERAL REMARKS.

The closing paragraph of my instructions required me to ascertain, as closely as possible, whatever local advantages and disadvantages might exist favoring, or interfering with, the construction of a ship-canal.

In presenting the results of observations made in complying with this order, it is not necessary that I should enter into any *comparative* statement of advantages and disadvantages, but simply—taken in its broadest sense—to present my convictions as to what conditions would be likely to be found favorable to the construction, maintenance, and successful operation of a canal by this route, and what unfavorable, exactly as though it were the only route in existence.

I have endeavored to look at this question without prejudice, and I give the following as the favorable and unfavorable conditions that have occurred to me with what attention I have been able to give the subject. Those accustomed to the contemplation and execution of great engineering schemes will doubtless see many more on both sides, while it is quite certain that, in the actual execution of the work, many contingencies and complications will arise that the best minds will now be unable to foresee. That such contingencies will be likely to array themselves on the unfavorable side cannot be doubted; still, it is by no means impossible that in practice some conditions may be more favorable than have been assumed, and the execution of the work correspondingly facilitated.

ADVANTAGES.

1. Shortness of the artificial channel required.
2. Good harbors. That on the Atlantic is all that could be desired, while on the Pacific there is deep water, with good holding-ground, and the region is seldom visited by violent gales.
3. The cutting mainly in rock or stiff clays. In such materials the amount of excavation can be reduced to a minimum. The clay will form stable embankments, as little liable to wash from rains and at the water-surface as any embankments can be, and its impervious character will greatly reduce losses of water from leaks and filtration.
4. The greater part of the work to be performed lies in a healthy region for the tropics.
5. Abundance of good timber for construction.
6. Proximity of heaviest work to the Pacific coast, rendering transportation of labor, plant, and supplies comparatively inexpensive.
7. Absence of high winds along the canal-line. Transit would be seriously impeded in any canal that should lie through a region subject to violent winds.
8. Freedom from liability to terrestrial convulsions of a nature likely to affect the permanency of the canal-works. This appears to me to be an important point. Such accidents cannot be guarded against, and a country in which they are of frequent occurrence can hardly be considered suitable for canal purposes.
9. Absence of large streams or of deep valleys to be crossed at a high elevation.
10. Friendly attitude of the inhabitants.
11. Fertility of the soil. Under proper management, the country in the vicinity of the proposed line could be made to produce the greater part of the supplies required for the subsistence of the laborers.

DISADVANTAGES.

1. The necessity of resorting to a tunnel. This, while it is no doubt practicable, involves great expense in construction; uncertainty in estimates of cost, and a probable increase in the difficulties attending transit, especially for large ships.
2. The steep descent of the Pacific slope, necessitating the grouping of a large number of locks, and thus increasing the liability of damage to the works.
3. Very heavy cuttings in the valleys of the Dognado and Chiri-Chiri.
4. Limited water-supply during dry seasons.

5. Liability to damage to the works from sudden floods. It is believed that this contingency is well guarded against, but the liability to sudden and violent floods in a hilly country subject to torrential rains cannot be overlooked.

6. Excessive rains, likely to wash away embankments, &c., while in course of construction, and to interfere generally with the progress of the work.

7. Shortness and uncertainty of the yearly periods well suited to the work of construction.

8. Undeveloped state of the country and scarcity of native labor.

9. Remoteness from the great commercial centers of the world.

GENERAL REMARKS.

In concluding this report, I have to state my belief that, with all the imperfections with which our survey is justly chargeable, it affords, in connection with those previously made by Commander Selfridge, all the data necessary to a reasonably close approximation to the merits of the Napipi route.

The progress of our survey developed an amount of work greatly in excess of what had been anticipated, and to accomplish our task, in an imperfect manner even, required the heartiest co-operation and the greatest personal exertions on the part of every member of the expedition, officers and men. That this hearty co-operation existed, and that these personal exertions were put forth, the results show. In my associates on this work I was most fortunate, and to one and all my heartiest thanks are due.

Lieutenants Eaton, Sullivan, and Paine are already so well known in connection with work of this character, that I am sensible of the fact that no words of mine can add to their reputation. Yet it is my duty to testify to the ability, zeal, and indomitable energy that they severally displayed in the performance of the severe labors of the past season.

To Lieutenant Eaton fell the unenviable task of carrying the survey through the dismal morasses near the Atrato. The sufferings of the party under his command engaged in that work can be inferred from the fact that not one escaped a severe attack of fever. It was only by the most stubborn perseverance, backed by most excellent judgment on his part, that an unbroken line of levels from the Pacific to the Atrato was obtained.

Lieutenant Sullivan's services in making reconnaissances for the development of the topography of the country, to say nothing of his other multifarious duties, were invaluable. To him belongs the credit of the system of reconnaissances that enabled us, with our small force, to obtain such accurate knowledge of the physical features of the region along the line. Severe labor was required of the party under his command that carried the survey up the rugged valley of the Doguado and across the divide to the Pacific. He also, by assuming charge of all matters relating to the transportation and preservation of stores, as well as the hiring and paying of native laborers, in dealing with whom much tact is required, relieved me of much care and labor, while to his thoughtful attention much of our comfort in camp was due.

Lieutenant Paine, in addition to his severe daily labors in the field, took general charge of the meteorological observations and of the experiments for ascertaining the flow of the Napipi. Those duties required from a half hour's to an hour's extra labor each day—no small matter when one's regular duties are of the most laborious and exacting character; but they were always cheerfully and carefully performed. His arrangements for determining slight changes in the level of the Napipi were ingenious, and his results may be relied upon as accurate. To his skill in handling the gradienter much of our rapid progress was due.

Ensign Barroll took hold of the work, which was entirely new to him, with such ability and zeal, as to compensate in a very short time for lack of previous experience. He was always ready for hard work, and possessed the valuable faculty of being able to turn his hand to anything on the shortest notice. His services throughout were of the greatest value.

To Assistant Surgeon Norfleet, also, the work of the expedition was a new experience. He was always attentive to the sick, and assisted constantly and effectively in the work of the survey outside of his own particular department.

To the care of Commander Selfridge, who was good enough to attend to the preparation of the

outfit for the expedition, we were indebted for an ample and palatable ration. So excellently were the provisions put up, that not a particle was lost by spoiling, and we had an abundance to the end, although our party was larger by one than was anticipated. I am also indebted to Commander Selfridge for valuable suggestions concerning the prosecution of the work and the preparation of its results.

To Captain Barrett and the officers of the Canandaigua we all owe our hearty thanks for courteous consideration, and an evident desire to forward in every way within their power the interests of the expedition.

I have elsewhere expressed my appreciation of the kindness of Mr. Menocal, in affording me assistance in the preparation of the data acquired by the survey, at the expense of frequent drafts on his otherwise fully occupied time.

To W. H. Hutton, civil engineer, and Alfred Duvall, civil engineer, of Baltimore, and to S. T. Abert, United States civil engineer, at Washington, I am likewise under many obligations for their kindness in replying fully and promptly to my requests for an expression of opinion on certain engineering questions.

Finally, I may say that on the part of every one with whom I have been brought officially in contact while engaged in this work I have received such ready and effective assistance that, with the most ordinary care on my part, success was assured.

Trusting that the objects for which the expedition was sent out have been as well fulfilled as circumstances would allow, and thanking the Department for the confidence it has reposed in me,

I am, sir, very respectfully, your obedient servant,

FREDERICK COLLINS,
Lieutenant.

Hon. GEORGE M. ROBESON,
Secretary of the Navy.

APPENDIX.

A.

REPORT OF LIEUT. J. G. EATON, U. S. N., COMMANDING PARTY No. 1.

INSTRUCTIONS.

UNITED STATES EXPLORING EXPEDITION,
Atrato River, February 1, 1875.

SIR: You will make a careful survey of the line proposed by Commander Selfridge from the Atrato River along the left bank of the Napipi to its junction with the Merindo. The proposed line, as laid down on the field-maps with which you will be supplied, will be followed as long as it presents no unfavorable conditions, but you will reconnoiter the ground carefully in advance of the survey to make sure of obtaining the best possible profile.

In deviating from the most direct line, in order to secure the lowest ground, you will bear in mind, first, that no curve of a less radius than 2,500 feet can be introduced into the projected line; second, that the increase in distance caused by the deviation should not overbalance the advantages offered by the lower ground.

You will, at the end of each day's work, and at all important points on the line, establish "bench-marks," conspicuously marked. The spot occupied by the rod must be carefully marked with copper tacks, and a minute description of the bench-mark entered in the field-book. The line, as finally determined and surveyed by you, will be marked by blazing trees on either side at short intervals.

You will make, at intervals of half a mile, or oftener if you think necessary, cross-sections of the route extending for 500 feet on either side of the line. You will extend these cross-sections, as frequently as practicable, to the Napipi, connecting, when possible, with some bench-mark of the former survey.

All water-courses and ravines, wet or dry, crossed by the projected line will be carefully located, and measurements taken to determine the maximum amount of water discharged by them during the wet season. A short reconnaissance should be made up all of these that are of any great size, to obtain an idea of the declivity of their beds and the extent of the water-shed drained by them. The elevations of their beds in reference to the bottom line of the canal should also be determined.

You will plot, as carefully as possible, on your field-maps each day's work, and also draw in the line for a canal as you may determine it. All reconnaissances should be made, when practicable, as a rough traverse; courses by pocket-compass; distances by pacing, and elevations with aneroid barometer or hand-level, in order that they may be plotted on the field-maps. On these maps should also be placed all information of whatever nature that may be obtained concerning the country along the line.

You will construct a profile of the line determined upon by you, taking the plane of the bench-mark on the Atrato as your datum line. It is proposed, by one or more locks, to raise the bottom of the canal immediately on leaving the Atrato to within 10 or 12 feet of the ground-surface. You will then distribute your locks, in favorable locations, in such a manner as to keep the bottom of

the canal on an average of about 15 feet below the surface of the ground. The locations of the locks, as thus determined, must be carefully marked.

You will procure and preserve specimens of all rock met with on the line, as well as on the river at different points. Especially, in case the canal-line comes very near the river, should you carefully note the character of the strata exposed on the banks and obtain specimens. Each specimen should be wrapped securely in cotton cloth, with a suitable tag bearing a number inclosed. A note-book should contain full particulars concerning each specimen, designated by its number.

Borings will be made with the instrument with which you will be provided, at intervals of half a mile along the line, and especially at the locations of the locks, to determine the character of the foundation. All specimens brought up by the borer will be carefully preserved in the bottles provided for the purpose.

Should you meet with any beds of clay suitable for "puddle," or with stone suitable for construction, specimens should be obtained, and full particulars as to location, extent, accessibility, &c., noted.

Obtain, also, all possible information concerning timber suitable for use in the construction of a canal.

You will note in your journal the state of the weather daily, stating particularly the number of hours each day that you may be prevented from working by heavy rains.

You will impress upon every member of your party who may be charged with any instrumental work the necessity of *accuracy*. Our object is to obtain full and reliable information as far as we go, and every one should feel that ample time will be allowed him to conduct his observations with all possible care. The officer running the gradienter is to be instructed to take out the distances corresponding to the micrometer readings, as well as the differences of level, at each station, and before moving the instrument. Sights exceeding 300 feet should be avoided, if possible, and enough intermediate levels should be taken to show with accuracy the surface-line of the ground. Intermediate sights need not be read nearer than *tenths* of feet, nor turn-points nearer than *hundredths*.

Ensign Barroll and Assistant Surgeon Norfleet will be directed to assist you in this work. Your party will consist of four seamen and twelve natives, or as many more as you may find necessary.

Lieut. J. T. Sullivan will assist you in making reconnaissances whenever he can find time after attending to his other duties.

Very respectfully,

FREDERICK COLLINS,
Lieutenant, Commanding Expedition.

Lieut. JOSEPH G. EATON, U. S. N.,
Commanding Party No. 1.

LOWELL, MASS., *September* 1, 1875.

SIR: I have the honor to make the following report of the operations of party No. 1 of the Darien Expedition of 1875:

In obedience to your order of February 1, 1875, I assumed command of party No. 1 upon the 8th of February. The party consisted of Lieut. J. G. Eaton, commanding; Ensign H. H. Barroll, Assistant Surgeon Ernest Norfleet, four sailors, including a cook from the United States steamer Canandaigua, and eight native peones, engaged at Vigia del Fuerte for the purpose of cutting trails through the woods, transporting provisions, managing canoes, &c. Lieut. J. T. Sullivan was also with the party at such times as his duties as commissary permitted, and aided me greatly in making reconnaissances. Camp Palma was established the same evening on the left bank of the Napipi, some twelve miles from its mouth. The provisions were landed, tents pitched, hammocks slung, and the customary routine of camp-life in the woods at once entered upon. The camp was located but a short distance from the most northerly bend of the Napipi, and in proximity to the proposed canal-line of 1871 and 1873. The morning of the 9th instant was passed in

arranging messes and the adjustment of instruments. On the 10th, a trail was cut to the intersection of the main line and the observers and rodmen practiced in field-work. As they had formerly acquired some experience at Aspinwall, they readily adapted themselves to the field-work, and on February 11 the first real work was done upon the line.

Some description of the manner in which the work was done is required in order to explain fully the difficulties encountered and the slow progress made. The gradienter being set up and adjusted, the meridian was obtained, the desired course set off, and a rodman established as far ahead on this course as the nature of the ground permitted—in no case more than 300 feet distant, and generally not 100. Alignments were then made on these two points, *i. e.*, the rod and the instrument, and stakes driven in advance for temporary use in guiding the macheta-men in cutting and opening a trail. The number of natives employed in this work varied from four to eight, and these were worked in two gangs, alternating in cutting and relief every hour. Owing to the dense undergrowth, the opening of a trail was slow work and hard labor. Upon level or nearly level ground, the advance of the instrument was continually retarded by lack of open trail, while among the hills the cutters were kept back by the slowness of the instrument; frequent settings being required, owing to the abrupt changes of level, and the slopes so steep, that time was necessary to find a spot where the instrument could be placed. Finding that these causes were occasioning delay, I had the trail cut by a prismatic compass, the gradienter following and marking the exact courses and the inequalities of the ground. The gradienter was run either by Mr. Barroll or myself, and Dr. Norfleet assisted as recorder, in addition to his duties in taking borings.

When possible, Lieutenant Sullivan assisted in reconnaissances. In these reconnaissances a hand-level was used for elevations and paced distances, with courses from a pocket-compass for traverses. In this way I endeavored to get a general idea of the country over which we were to pass two or three days in advance of the gradienter and main line. I was thus enabled to direct the movements of the main party to much better advantage, and avoid, as far as could be avoided, such hills as previous knowledge had developed. By means of these reconnaissances a comparatively large section of country in the vicinity of the line surveyed was opened, and a serviceable knowledge of its general topographical features obtained. Whenever any considerable elevation was encountered, its summit was followed till the end was reached, or till it was evident that too long a detour would be required to pass around it. When the latter was the case, the main line was directed to the lowest summit-point, when this could be reached without too abrupt an angle. Owing to this cause, most of the hills below the Pedagacito were crossed at the most favorable points. A few opposite the Amboribido might be crossed more favorably, though I am of the opinion that they cannot be avoided by any line on the north bank of the Napipi. All streams of any size which were crossed by the canal-line were cross-sectioned and their general course determined. Borings were taken whenever the nature of the ground would seem to indicate any change of strata. To reach a depth of 10 feet required the hard labor of five men and an officer for an entire day. The great weight of the screw and the tenacity of the clayey subsoil rendered the lifting of the screw an hour's work. The borings were uniformly conducted by Dr. Norfleet, with such aid as I could spare him. A bench-mark was established on some large tree at the end of each day's work. The bench was marked with three copper tacks, and upon a large blaze above was its number also in tacks. A description of each bench-mark was entered in the field-book as soon as made.

The party usually breakfasted at 6 a. m. and before 7 all hands were at work upon the line; the cook alone remaining in camp to prepare the dinner. An hour's rest was taken for lunch of hard-tack and bacon at noon, and work was generally stopped in time to reach camp by 5.30 p. m. This gave time to bathe, put on dry clothing, and finish dinner before dark. All hands turned in early, and no watch was kept at night. The field-books were copied into smooth copies every evening, position of last bench-mark plotted on chart, and course for ensuing day determined. All the ridges and streams met with were outlined and the topography sketched in as fast as known.

My instructions were to connect with the Atrato from Camp Palma and then to work to the westward till the junction of the Merindo with the Napipi was reached, keeping as straight a course

as practicable, always on the north bank of the Napipi, and curving toward the river in the large southerly bends only when forced to do so by hills on a more direct line.

In accordance with these instructions, an offset of 300 feet was run from near Camp Palma due north until the proposed line of canal was reached, when the course was changed to north 90° east. The trail had scarcely left the river-bank when marshy ground was encountered. As the line advanced pools of stagnant water were met, the ground became soft and miry, and the only trees found were *quita sol* and white palms. Despite the unpromising nature of the country, the work was pushed ahead, the men sinking to the knees at every step in the ooze, and frequently requiring assistance to extricate themselves. Wishing to assure myself as to the extent of the swamp, I kept on till farther progress was utterly impracticable. I had now traversed 3,200 feet from B. M. No. 1, E., near the river. The ground was everywhere covered with water, and beneath the water the soil was completely saturated and of the consistency of mush. The peones who were familiar with this swamp told me that it extended to the banks of the Atrato; a statement I afterwards found to be true, There was nothing for it but to abandon this part of the work until the hot sun and fresh trade-winds of the dry season had caused sufficient evaporation to render it passable. An attempt the following day to run from B. M. 1, E., to the westward met with a similar result, the characteristics of the country being the same as on the previous day. Finding that nothing could be done here at this time, I determined to move camp some six miles up the river and make another effort at that point. A boring was taken at B. M. 1 and a depth of 13 feet reached, showing alluvial soil similar to that previously found on the banks of the Atrato. My next camp, Camp Pavo, was established eighteen miles from the mouth of the river, and the party and stores moved there by canoes.

Upon proceeding to work from Camp Pavo, hills varying from 50 to 100 feet in height were found, and as these increased in size and height as they receded from the river, I established a bench-mark on a northerly bend of the river, and worked thence to the eastward. The country was so broken that it was necessary to cross several of these ridges. Reconnaissances developed the general direction of their summits, and showed that they were offshoots from spurs of the main divide between the Napipi and the Opogado, descending as they neared the river, and in some cases butting on the river itself, with bluffs of 20 to 50 feet elevation. More commonly the foot of the ridge was four or five hundred feet back, with level land intervening. Owing to the sharp bends of the river, it was impossible to run the line through these foot-lands in most cases; still, I availed myself of them whenever practicable. About 9,000 feet to the eastward of B. M. 9, E., the last of the ridges was crossed, and ground reached which was nearly level, and evidently subject to overflow during the height of the rainy season. I carried the work as far in this direction as could profitably be done from our camp. The men were conveyed to the nearest point of the line from the river in canoes, and then reached their line by an offset from the river-bank. The Braso Muriel, one of the three mouths by which the Napipi discharges its waters during the rainy season, was crossed, and carefully cross-sectioned. At this date no water was flowing through from the river, but the drainage of the surrounding country was finding an outlet through it. From this point to the Atrato there are but a few low detached hills, and these could have been avoided by the line had time admitted of the delay necessary to run the curves. These hills are composed of a tenacious red clay, and seem to owe their existence to their ability to resist detrition from the heavy rains.

B. M. 4, E., having been established as far to the eastward as work could be carried from camp, the line was resumed from B. M. 9, E., and carried thence to the westward. The valley of a large quebrada flowing nearly east had been previously developed, and up this valley the survey was carried. At a point where the valley had narrowed to 500 feet I found it necessary to leave it and strike at once across the hills which lay in our path. These were the ridges in the vicinity of the Amboribido, and although the line was piloted over the most favorable depressions, the work was very tedious and arduous. The summits of all these ridges were very narrow, not more than 6 feet in width, and the sides precipitous. So steep were the slopes, that stations for the instrument could only be found after much perseverance. While at work here, camp was moved still higher up the river, and the new camp designated Camp Loma. With regard to these hills, I feel confident that while the line surveyed is not the best which might be found; still none materially better

could be obtained without changing the river's channel at some of the sharp bends and carrying line and river both more to the southward. After crossing the Amboribido hills, level ground was met for a mile, when we again struck hills crowded together in such profusion, that there was no level ground between. The country here is a complete network of ridges, which begin nowhere and are present everywhere. Each is cut off from the next adjoining by ravines, and these ravines uniting form a quebrado whose valley is generally a hundred feet wide. In hopes of avoiding these ridges, I pushed the reconnaissances into the interior as far as the canal-line could be carried, but in every case the ground rose so rapidly, that I was forced to abandon this hope, and hug the river-bank for lowest ground as closely as the curves and straights would permit. These hills have a depth of 5 to 10 feet of earth, and the remainder is solid trap rock, as evidenced wherever a a bluff terminated upon the river-bank.

Upon March 14 the line had progressed so far that another move of camp was necessary, and accordingly Camp Relief was established six miles higher up the river and thirty miles from its mouth. Upon the 15th instant you and your party joined us, coming from above, and up to the 18th instant both parties worked in unison. On the evening of the 19th party No. 1 was reorganized, and then consisted of Lieutenant Eaton, commanding; Ensign Barroll, three sailors, and four peones or macheta-men. One month's rations were issued; and my instructions were to return to Camp Palma, connect bench-marks 4 and 1, and thence to work eastward, and strike the Atrato, if possible. If not possible, to move camp to the Atrato, near the point where the line was to connect therewith, and make another attempt from that point. Previous information with regard to a large lake, into which the Braso Muriel empties, had led me to hope that it might prove of use to us; and I was further instructed to examine this lake, and, should it be serviceable, to connect a line of levels therewith, and obtain such soundings and shore-line as time would allow.

Up to this date the health of the party had been exceptionally good. The precautions observed as to dry clothing to sleep in, dry tents, and preventive doses of quinine had kept every one in excellent health and spirits. I am, moreover, of the opinion that to the westward of the Braso Muriel the country is as healthful as any in the tropics.

At daybreak on the morning of March 19 my party embarked in two large canoes, and bidding good-by, started on our way down the river. We had expected to reach Camp Palma early in the afternoon, but the river was very low, and passage over the palisades was very slow and difficult. It was long after dark when camp was reached. The following morning levels were resumed from B. M. 4, E., and, the ground being firm and land level, excellent progress was made till 3 p. m., when, a sudden and heavy shower coming up, B. M. 3, E., was established. The next day the line was connected with B. M. 1, E., and a line of check-levels run between bench-marks 2 and 1, which differed 0.47 feet from previous results. This was undoubtedly owing to the swampy nature of the ground when the first levels were taken.

I now deemed it best to proceed at once to the Atrato, and examine the lake before mentioned. Camp was broken on Saturday, the 22d instant, and the party, embarked in canoes, reached the Atrato early in the afternoon. Sunday was observed as a day of rest, and on Monday, leaving Mr. Barroll with orders to follow down the Atrato as soon as the canoes which had been sent to Vigia should return, I proceeded in a chingo down the Atrato some fifteen miles and reconnoitered Lake Muriel. To my surprise, the lake was dry, and its bottom covered with a short green grass that gave it a prairie look, delightful to one whose vista had been so narrowly circumscribed for weeks. The form of the lake is elliptical, and its major axis, which lies northwest and southeast, has a length of three miles, and the minor axis about two; through the center runs the channel cut by the Braso Muriel during the dry season. From the position of the lake as to the bends of the Atrato, it could not be made use of by the canal line. During the rainy season the average stage of water gives a uniform depth of 6 feet, and in extreme rises its banks are inundated to a further depth of 3 feet. Being satisfied that this lake was not available, I returned to my party, which had formed a camp on the right bank of the Atrato and at a point immediately opposite the proposed easterly terminus of the canal-line. A bench-mark was established on the left bank and all the surrounding trees and underbrush cleared. The bench-mark tree was blazed and marked in copper tacks as follows:

U. S. N., 1875.
B. M. 27, E.

A line of soundings was run across the river, showing a depth of 6 fathoms in the channel, and shoaling to 3 fathoms near the banks. The Atrato at this time was very low, the high-water mark being about 30 feet and average height 12 feet above the then level. The width between the banks proper was 850 feet. With the water-surface as a datum point, the height of the bench-mark was determined, and work begun on the main line to the westward.

The distance to the nearest bench-mark on the Napipi was nearly five miles, and my intention was to run directly towards it. This I found to be impossible, as impassable swamps blocked the way. The line as surveyed skirted the northwestern edges of a large swamp to the south, called by the natives "Palmerita." Whenever opportunity offered, the course broke more to the west, until, in order to avoid another wet swamp on the north, called "Murielito," a course of south 77° west was taken and generally followed. As soon as the river-bank had been left, the levels fell constantly, until they showed an elevation of 12 feet less than the bank and but 6 feet above that of the river. This fact accounts for the existence of the swamps, which were yet lower than our line. During the great rises of the Atrato and Napipi in the wet season, the rivers overflow their banks and inundate the surrounding country. At such times the waters are turbid with sediment brought down from above, which raises the banks till they assume the character of dikes to the back lands. Hence the back country, once overflowed, must depend for its drainage on a few sluggish rivulets or brooks, whose mouths are blocked by every rise, and barely opened at a low level before another rise of the rivers again dams them up.

As the line advanced to the westward, coarse swamp and hummock grass was met, and rendered the clearing of a trail a very arduous work. There were very few trees, chiefly *quita sol* palms, whose trunks were studded with thorns about two inches in length and sharp and strong as needles. Insects of all kinds abounded, the ants being particularly numerous. Every tree and shrub, every blade of grass, was covered with them, and we experienced much pain and annoyance from their venomous bites. We were favored with clear days, but the intense heat of a vertical sun, the utter absence of wind, the lack of wholesome drinking-water, and the marshy condition of the ground rendered our work extremely difficult and trying on all. Open-water swamps existed on both sides of us, and we were very fortunate in finding what may be aptly termed a natural causeway, over which a reliable line of levels could be carried. Extreme care was requisite in the settings of the instrument, owing to the quaking bogs beneath. Water could be obtained at a depth of 2 feet, and a pole shoved down 14 feet met no resistance. As it was imperative that this work should be completed before fresh rains had made it still harder to perform, officers and men were worked from 5 a. m. till 7 p. m. By this means a point was reached whence a connection could be made from B. M. 1, E., and, leaving Mr. Barroll with orders to push on to the westward, I returned up the Napipi to Camp Palma to assist in connecting the line. While making this connection, I was attacked by fever and confined to my hammock, and Mr. Barroll, though suffering from a severe sprain, completed the line of levels; and there was now a clear line from the Atrato to within six miles of the Pacific. Thus ended the severest labor of party No. 1, a labor which had required the utmost energies of every one, and which owed its success to the untiring labors of all and their determination to get through at all hazards. Upon its completion every white man was sick with fever acquired in the swamp. I was forced to wait several days before I could set out for the Merindo. Two days were occupied in reaching headquarters at that point.

In conclusion, the country between the Atrato and B. M. 26, E., may be divided into three divisions, and the topographical characteristics of each division are distinctly marked. The first of these divisions extends from the Atrato to the foot-hills above the Braso Muriel, and is a plain having a gradual slope towards the Atrato, and is subject to inundations during the rainy season. The ground is mainly alluvial; has few traces of underlying rock. Blue clay was found generally at a depth of 8 feet. There are few streams, and what there are are sluggish and small. The woods are mostly composed of palms, although an occasional bácarrá tree is found, and are remarkably free from underbrush in many places. The level of this plain is uniformly lower than the banks of the adjoining rivers.

The second grand division extends from the Braso Muriel to B. M. 21, E., and is broken by steep hills and spurs from the main divide between the Opogado and the Napipi, which at this

point lies near the latter river. Directly opposite the Amboribido the ridges attain a considerable elevation, and terminate by cliffs on the river bank. In the exposed strata the loam has a depth of from five to ten feet, and below is trap-rock, seamed and disintegrated by the action of the hot sun and heavy rains. In places the rock may be whittled with a knife, but at a trifling depth the rock became so hard that the knife made no impression. With the exception of one level space of 5,000 feet, the valleys intervening between the hills have rarely a greater width than 300 feet. The ravines, dry when our line crossed them, were very numerous.

The third division, from B. M. 21, E., to B. M. 26, E., has long level stretches interrupted by an occasional ridge of moderate elevation. The absence of small streams gave evidence of the level character of the land. Red and blue clays were also found on this portion.

The officers and men of the party were always willing and anxious to promote the success of the work. Had it been otherwise, our task could not have been completed in the time allowed us. I am particularly indebted to Ensign H. H. Barroll for valuable service and untiring energy in the prosecution of the work. Assistant Surgeon Ernest Norfleet afforded much assistance by acting as recorder, and performed his duties to my complete satisfaction. A more harmonious party I have never seen; and I attribute much of the success of our labors to the hearty co-operation of every one engaged.

I am, sir, very respectfully, your obedient servant,

JOS. G. EATON,
Lieutenant, United States Navy.

Lieut. FREDK. COLLINS, U. S. N.,
Washington, D. C.

B.

REPORT OF LIEUT. J. T. SULLIVAN, U. S. N., COMMANDING PARTY No. 2.

INSTRUCTIONS.

HEADQUARTERS UNITED STATES EXPLORING EXPEDITION,
Junction of Napipi and Merindo Rivers, April 1, 1875.

SIR: The survey for the location of a route for a ship-canal from the point of crossing the Napipi, already established, to Chiri-Chiri Bay, on the Pacific, will be continued under your direction.

Your familiarity with the manner in which the survey has thus far been conducted renders any general instructions unnecessary.

The special points requiring your attention will be the location of the eastern and western portals of the proposed tunnel, and the most favorable site for the locks required for the descent to the Pacific.

In regard to the first, your line will follow the general direction of the valley of the Doguado, keeping as near to the river as may be necessary to secure the best ground until an elevation is reached that would require a cutting of more than 200 feet in depth. Such an elevation will be reached at a point 189 feet above B. M. No. 1, C., but should that point be found on the summit of a sharp spur crossing the line, the survey should be continued until the *average* elevation of two such spurs and the intervening valley equals or exceeds 189 feet.

The point thus determined will mark the location of the eastern face of the tunnel. Having established it, you will carry your line to the bed of the Doguado, and continue your courses, distances, and levels up that stream to a convenient point for crossing the divide and descending to Chiri-Chiri Bay. Here you will give your attention to finding the most favorable location for the locks required for the descent. This will probably be found in the valley of the Chiri-Chiri River, which you will examine carefully, not only running a line down it to connect our levels with bench-mark No. 1 of the survey of 1873, but making as many cross-sections as may be necessary to afford sufficient data for calculating the excavation required by the locks, however they may be placed.

The location of the western face of the tunnel will be determined: first, by the elevation, which of course must equal that of the eastern face; second, by the most favorable location for the locks.

If bench-mark No. 1 of the survey of 1873 can be positively identified, you will connect your line of levels with it; otherwise it will be necessary to establish a tide-gauge at Chiri-Chiri, and spend whatever time you may be able to spare in obtaining observations for the reduction of your last bench-mark to the plane of mean tide.

You will be careful to secure specimens of the earth or rock met on the line of survey, especially when the line may be crossed by a deep quebrada, in which case the character and depth of the exposed strata should be noted in the field-book, and specimens of each obtained. Any data that may have any bearing on determining the depth of the stratum of earth overlying the bed-rock and the character of that rock are important and should be secured.

In case you should discover any indications of limestone, or of any stone suitable for construction, you should obtain all possible information concerning the location and extent of the beds in which they may be found, noting especially their accessibility and proximity to the canal-line.

Note in your journal the character of the weather daily, stating particularly the number of hours during which you may be prevented from working by heavy rains.

All ravines and water-courses, wet or dry, passed over by the line of survey should be carefully measured and the cross-section entered in the field-book.

In locating your line, remember that curves of a less radius than 2,500 feet are inadmissible.

It is desirable to obtain by reconnaissance or otherwise, the profile of the surface of the ground over the tunnel, but this is a secondary consideration, and need not engage your attention till the more important data required are all secured.

Preserve carefully the original data in all cases, and keep smooth copies up to date to guard against accidental loss.

Lieut. S. C. Paine and Assistant Surgeon Norfleet have been directed to report to you to assist you in this work. In addition, you will hire as many natives as may be necessary.

Very respectfully,

FREDERICK COLLINS,
Lieutenant, Commanding Expedition.

Lieut. J. T. SULLIVAN, U. S. N.,
Commanding Party No. 2.

ASPINWALL, UNITED STATES OF COLOMBIA, *May* 9, 1875.

SIR: I respectfully report that, in obedience to your orders of April 1, 1875, I assumed charge of surveying party No. 2 on that same date, and immediately proceeded to carry out your instructions.

Lieut. S. C. Paine was placed in charge of the instrumental portion of the survey and Assistant Surgeon Ernest Norfleet was detailed to aid him.

It was considered advisable to limit the number of the party, as the work was to be carried through a tract of country which offered many obstacles to the forwarding of supplies, and the object sought was to reduce the quantity of provisions to be transported by limiting the number to be subsisted to a minimum working force.

The usual routine of working was carried on, the party generally leaving camp at seven o'clock and returning at five. The instrument was carefully adjusted every morning, and after returning to camp the work of the day was proved, copied into the smooth field-book, and plotted on the chart. This was no small labor after a day's work, and frequently we were kept up till quite late till it was finished.

Whenever it was practicable, I made reconnaissances ahead of the main line and secured approximate elevations by use of the hand-level, and the traverse by pocket-compass and pacing. From the data furnished by these reconnaissances I was enabled to lay out the best course for the line to take on the following day, and whenever it became necessary to lay in a curve your instructions were carried out, as no curve of a shorter radius than 2,500 feet was introduced.

The work of leveling, under the immediate charge of Lieutenant Paine, was carried on with a conscientious regard for accuracy. The elevations obtained by use of the hand-level were suffi-

ciently accurate for the purpose of reconnaissance, and could generally be relied upon within three or four feet. It frequently happened when it was possible to connect with a station on the main line to find the elevations agreeing within one foot.

The work was carried on with but few interruptions from the weather, although after the 11th of April there was a great deal of rain, but fortunately most of it fell during the nights and on camp-moving days. The party lost two field-days on account of rain, on one of which they remained in camp altogether, and on the other they had reached the point after an exceedingly hard walk of two miles, when rain set in and continued the remainder of the day. The party remained in the field until afternoon, in hopes that by a cessation of the rain they might be able to do some work on the line, but no evidence of clearing weather, and a rising river, made them return to camp.

The line of survey is naturally divided into three divisions: the first from the basin, at the junction of the Napipi and Merindo Rivers, to the eastern portal of the tunnel; the second by the bed of the river Doguado to the main divide and across it to the Pacific, connecting with bench-mark No. 1, 1873; and the third from this point up the bed of the Chiri-Chiri to the western portal of the tunnel.

The first portion of the line after leaving the basin passes over flat country for only 1,200 feet, when it encounters the end of a spur, which it carries to the Merindo-Doguado divide, crossing it at an elevation of 216 feet. This point of crossing is in close proximity to the Napipi, and was determined upon as the place of least elevation, and the best to encounter the divide, from an extended reconnaissance along the divide and several of its spurs on the Doguado slope. Had the line followed a more direct course, it would not only have passed over a greater elevation, but would have crossed the spurs diagonally instead of at right angles. After leaving the divide the line encounters spur after spur, which it crosses at rapidly increasing elevations, until it reaches and passes for a short distance the point where open cutting terminates and tunneling begins.

The spurs are all connected to the dividing ridge as the veins of a leaf are to the principal vein, and have minor spurs shooting off from them. They are uniform in slope, having a rise of about 1.5 to 1, and a narrow crest which in many places can be straddled. The ridges are of solid rock, having an average of eight feet of hard clayey surface-soil, which on the steep slopes is prevented from washing away by the intertwining roots of a densely grown forest.

Along this division of the line the rock as seen exposed in the ravines was trap, and occasionally large masses of flint were seen. Specimens of each variety of rock met with have been secured, and the locality where found properly recorded.

Having obtained a permanent elevation greater than that which determined the point of tunneling, the line was carried to the Doguado, and up that river to the main divide in the vicinity of camp 2, 1873.

There being no set courses to follow and no cutting required, the line advanced rapidly at the rate of 1.25 miles a day for six field days, which brought it in the vicinity of the main divide and near the point where the line of 1873 crosses it.

The Doguado is a large mountain stream, and in that portion over which the line passes is exceedingly wild and rugged. In the distance passed over, seven and a half miles, it has a fall of nearly 600 feet over a bed of rock filled with huge bowlders and large stones. The falls are numerous and remarkably beautiful. Before reaching the lower portion of the river, where the fall is more gradual, it flows through a series of four gorges which it has worn through the solid rock. These gorges are from 10 to 15 feet wide, and the cliffs of dark colored rock are from 20 to 60 feet high. The pools being very deep, the water looks almost black, and adds to the somber aspect, which is only relieved by the numberless cascades which fall from the adjoining cliffs.

Throughout the portion followed by the line the river winds around the bases and ends of ridges, and there is not in any single locality an acre of flat country. In the vicinity of camp 2, 1873, the river has a more moderate fall, and for a distance of about a mile apparently flows through a table-land.

Leaving the river the line was carried to the trail of 1873, and, following this, crossed the divide at an elevation of 780 feet. Following down a spur on the Pacific slope, the beach was reached and the line connected with bench-mark No. 1, 1873, the elevation of which, as determined by our levels, is 12.7 feet above mean tide. The distance of this bench-mark from where we left the Do-

guado is 7,200 feet, but a direct line to the beach is much shorter, as the beating of the surf was plainly audible in our camp at the headwaters of the Doguado.

The selection of the best location for the western terminus of the canal was easily determined, as the valley of the Chiri-Chiri was the only place where the necessary horizontal distance could be secured for the locks required. Accordingly, a line having as its initial point bench-mark No. 1, 1873, was carried up the bed of the Chiri-Chiri until an altitude of 354 feet was obtained, being 14 feet higher than the point which determines the western portal of the tunnel.

The Chiri-Chiri is a small mountain stream, and drains a small area of country lying between the spur upon which the main line runs and another large spur about one mile to the northward. It has its rise near the summit of the divide, and, having such a short distance to discharge in, its fall is very rapid. The lower part of the stream is about 50 feet wide, but within a distance of 3,000 feet from its mouth it becomes much narrower, and when the line ended it was only 20 feet wide. Its bed is of hard rock and is filled with bowlders. On each side of the stream the banks rise precipitously and run up into hills.

In order to obtain data for the approximate location of the locks and the amount of excavation needed, I intended running a series of seven cross-sections up to the summit-level of the canal, commencing at an elevation of 20 feet above mean tide and taking each cross-section at a regularly-increasing altitude of 20 feet. The first of these cross-sections was commenced and was advancing very slowly on account of the difficulty of obtaining settings for the instrument, when the work was abandoned in accordance with orders from you, received by me on the 29th April. By these orders I was instructed to stop work and return with the party to headquarters, using the utmost dispatch, as the Canandaigua's boats were awaiting us at the mouth of the Napipi, and were limited as to time. These orders were received about noon, and, returning immediately to camp, preparations were at once made to cross over the divide that afternoon to Camp Alto. Everything in the way of camp-gear and provisions not actually necessary was left behind that we might go traveling light. On the morning of the 30th April the party breakfasted by candle-light, and, with knapsacks, shouldered, awaited daylight to take the trail. Light loads and light hearts made the journey back to headquarters a remarkably swift and comparatively easy one.

Previous to connecting the line I had made a reconnaissance along the main divide to the northward for a distance of about a mile. I experienced very little difficulty in keeping the divide and found it running at about the same general elevation as where the line crosses it. The principal object of this reconnaissance was to locate and connect with it an intended barometrical reconnaissance over the line of the tunnel to B. M. 38, S., the point where the line left for the river, and thus secure a fair profile. The sudden recall, however, precluded the possibility of accomplishing this. My arrangements for making this reconnaissance were to start the Indian Bajelita and his companions, as soon as their services could be spared, to cut as straight a trail as possible to B. M. 38, S., and in returning to headquarters, after finishing the work on the line, I could use this trail, traveling light, letting the party return by way of the river. Knowing the task was a hard one, I did not broach the subject to the Indians until I had flattered them upon their knowledge of the country and their superior tact. They were not stimulated by this dose of flattery, but received it with distrustful looks, having received an inkling of what I was ultimately going to propose to them from a conversation which they had previously overheard. Coming to the point and telling them what I expected them to do, they looked exceedingly unhappy, pleaded sickness, and, enumerating the many obstacles to be overcome, expressed their unwillingness to carry out my orders. The matter was allowed to rest here through a motive of policy, thinking that when the line was connected and we were about to start on our return the Indians would be in better spirits and willing to carry out my plans. Being obliged to leave the field sooner than expected, these arrangements were upset, and I was obliged to return without the profile over the line of tunneling. From their knowledge of the country the Indians knew that the proposed trail would have to cross every spur from the Merindo-Doguado divide between the points of departure and B. M. 38, S., which would make the work of cutting and climbing over these steep ridges very difficult. To trails of this kind they are not at all partial, preferring to obtain better walking, at the expense of distance, by following the crests of ridges. An Indian trail from one river to another, instead of attempting to follow a generally straight course, would ascend a spur to the

divide between the rivers and follow this until a spur on the other slope was reached, by which they would descend to the other valley. It has generally been supposed that their object in having these trails follow high ground was to secure better walking during the season of floods; but the fact is they secure better walking at all seasons by following the ridges instead of crossing them.

Owing to the greater part of the work being beyond the head of canoe navigation, the labor of camp-moving and of forwarding supplies was very severe. This work was carried on as expeditiously as possible, that the survey might not be delayed; and particular attention was given to the selection of the sites for our camps and to their construction with a view to comfort. Experience teaches that the extra time taken to make a camp comfortable and attractive is far from being lost. Returning from the field weary and exhausted, wet and dirty, one will anticipate the pleasures of a good camp; and on arriving there, after indulging in the luxuries of a bath, clean clothes, and a well-cooked meal, will become forgetful of the hardships of the day, and from this relaxation be the better fitted for the work on the morrow.

The materials of which the ration was composed were excellent, and in the hands of our cook, a zealous and painstaking man, were served up temptingly and in a surprising variety. The ration was bountiful, and, with ordinary care, generally ran ahead. The item of pickles was the only one to fall behind; and it would be well to suggest a plentiful allowance to any future expedition. The bread, although compactly stowed, was bulky, and I think that fully as much as one-half the allowance could with great advantage be supplemented by corn-meal.

The health of the party was generally good, and their spirits dependent on the progress made and the condition of the weather. A rainy day in camp would lower the spirits of the party more than anything else.

Throughout the existence of the party the greatest harmony prevailed, and all work was faithfully and cheerfully executed.

Very respectfully,

JNO. T. SULLIVAN,
Lieutenant, U. S. N.

Lieut. FREDERICK COLLINS, U. S. N.,
Commanding U. S. Exploring Expedition.

C.

REPORT OF LIEUT. S. C. PAINE, U. S. N., ON METEOROLOGICAL OBSERVATIONS AND EXPERIMENTS FOR ASCERTAINING THE FLOW OF THE NAPIPI.

BANGOR, MAINE, *July* 26, 1875.

SIR: In obedience to instructions, I have the honor to submit the following report of the result of the meteorological observations and the experiments for ascertaining the water-supply of the Napipi River during the months of February, March, and April of the present year.

On arriving at headquarters on the 13th February, observations were commenced and continued, with the exception of two weeks, at that point till the 29th April, when the party started upon its return to the Canandaigua. All barometrical observations must accordingly be referred to this point, which is 150 feet above the sea-level.

On the same day a careful cross-section of the Napipi was made immediately below the junction of that river with the Merindo. This section was established in the following manner: A bench-mark was first made on a tree on the bank as a point of reference. From this bench-mark to the river-points in line were established five feet apart, and their height determined relatively to that of the bench-mark by means of the level. From the water-level to the opposite shore accurate soundings were taken at like distances, and from these soundings the mean ordinate was computed. It was only necessary then, at any future time, to find the water-level by one setting of the level, apply the difference between the level as found and that on the initial day to the mean ordinate, measure the distance from the bench-mark to the water's edge, and with the velocity of the current the data was at hand for computing the volume.

This method resulted not only in a great saving of time, which with a small party was very desirable, but enabled us to take accurate cross-sections when, by reason of a rise and increased velocity of the river, soundings would have been very liable to error.

The velocity of the current was found by means of a "current-meter." The mean of several observations of the surface-velocity was taken, and the mean velocity was taken as 0.84 of the result.

The past season was an exceptionally dry one, the entire rainfall amounting only to 10.42 inches, and the volume of the river is probably never less than the minimum volume as recorded.

The great and rapid changes to which the volume is liable is shown by an inspection of the record for the 10th and 11th of April, when a rainfall of 1.84 inches caused an increase in the volume from 340,000 cubic feet per hour to 11,165,000 cubic feet.

The annual change of seasons comprises two dry and two wet, the middle of each corresponding respectively to the arrival of the sun at the equinoctial and solstitial points.

The average temperature at midday, as shown by a thermometer exposed to the sun, was 96.7° Fahr., the maximum being 114° and the minimum 82° Fahr.

The prevailing wind blows from the southward, sometimes varying a little to the east or west of that point. A fresh breeze usually springs up about 10 a. m. and lasts till nearly sundown.

The accompanying charts (see Plate IX) show the barometric and thermometric heights, the relative humidity of the atmosphere, the rainfall, and the daily volume of the Napipi. The readings of the instruments are given for every four hours with the exception of 12 p. m.

The same data is also arranged in tabulated form and appended to this report.

The following instruments were used in obtaining the foregoing data:

One aneroid barometer with attached thermometer, marked "Josh. T. Large, 27,552."

One aneroid barometer, compensated, graduated to 10,000 feet of elevation, marked "Jas. Green."

Two delicate ivory scale thermometers, marked "A," "B," "1804, Jas. Green." The former of these was used as a wet bulb; the latter, dry.

Two ordinary ship's thermometers, marked "2907" and "2842," "Jas. Green."

One rain-gauge, made also by Jas. Green, consisting of a cylindrical copper vessel, area 20 square inches, and a glass vessel graduated to measure the rainfall to one hundredth of an inch.

One current-meter, by Jas. Green.

Very respectfully,

SUMNER C. PAINE,
Lieutenant, U. S. N.

Lieut. FREDK. COLLINS, U. S. N.,
Washington, D. C.

Table showing the meteorological observations and the average hourly volume of the Napipi River during the months of February, March, and April, 1875.

[Lieut. S. C. Paine, United States Navy, observer.]

NOTE.—The column marked "vol." shows the average hourly flow of the Napipi for each day in cubic feet. The barometrical record is of value only as showing the variations in the pressure of the atmosphere. The correction which should have been applied to reduce the readings, was lost after it was too late to obtain another comparison with the standard.

The letters in the "weather" column have the following significations: *b*, blue-sky; *c*, clouds; *o*, overcast; *p*, passing showers; *r*, rain; *t*, thunder; *l*, lightning.

Date.	Hour.	Dry bulb.	Wet bulb.	Relative humidity.	Barometer.	Weather.	Wind.	Rain.	Vol.
Feb. 13	4	76	74	.88	30.57	b. c.	S'ly.		505,919
	8	78	76	.89	30.59	"			
	12	83	78	.76	30.55	"			
	4	80	76	.80	30.46	"			
	8	76	75	.95	30.49	"			
14	4	73	71	.89	30.54	"	S'd & E'd.		577,767
	8	74	72	.89	30.57	"			
	12	85	78	.68	30.52	"			
	4	83	81	.90	30.48	"			
	8	76	76	1.00	30.49	"			
15	4	74	74	1.00	30.51	c.	S'ly.	4/100 in.	539,392
	8	75	74	.94	30.53	"			
	12	84	78	.72	30.53	"			
	4	78	77	.95	30.50	c. r.			
	8	76	75	.95	30.52	b. c.			
16	4	73	73	1.00	30.56	"	S'ly.		594,479
	8	77	75	.89	30.59	"			
	12	82	79	.85	30.58	"			
	4	83	79	.80	30.52	"			
	8	76	75	.95	30.53	"			
17	4	72	71	.94	30.56	"	S'ly.		500,232
	8	77	73	.80	30.57	"			
	12	84	77	.68	30.56	"			
	4	84	77	.68	30.50	"			
	8	76	75	.95	30.52	"			
18	4	72	72	1.00	30.54	"	S'ly.		463,289
	8	76	74	.89	30.58	"			
	12	84	78	.72	30.53	"			
	4	84	78	.72	30.48				
	8	76	75	.95	30.49	b.			
19	4	73	72	.94	30.52	b. c.	S'ly.		536,752
	8	76	73	.85	30.52	"			
	12	84	78	.68	30.48	"			
	4	80	75	.76	30.44	"			
	8	74	73	.94	30.46	"			
20	4	73	71	.89	30.47	"	Calm.		458,641
	8	75	73	.89	30.53	"			
	12	84	77	.68	30.49	"			
	4	83	79	.80	30.48	"			
	8	75	73	.89	30.50	"			
21	4	74	73	.94	30.53	"	S'ly.		458,641
	8	77	75	.89	30.57	"			
	12	89	80	.61	30.52	"			
	4	80	75	.76	30.47	"			
	8	75	73	.89	30.50	"			
22	4	74	73	.94	30.55	"	S'ly.		452,019
	8	76	73	.85	30.57	"			
	12	84	83	.95	30.52	"			
	4	79	75	.80	30.49	"			
	8	75	73	.89	30.50				
23	4	73	72	.94	30.53	o. c. r.	S'ly.	68/100 in.	553,776
	8	75	74	.94	30.54	c.			
	12	85	77	.65	30.49	"			
	4	82	78	.80	30.47	b. c.			
	8	76	76	1.00	30.49	"			
24	4	73	72	.94	30.52	"	S'ly.		453,993
	8	77	75	.89	30.56	"			
	12	87	78	.62	30.49	"			
	4	81	78	.85	30.46	"			
	8	77	75	.89	30.49	"			
25	4	74	74	1.00	30.51	"	S'ly.		451,951
	8	79	76	.85	30.52	"			
	12	84	77	.68	30.49	"			
	4	84	80	.80	30.46	"			
	8	77	75	.89	30.50	"			
Feb. 26	4	75	74	.94	30.52	"	S'ly.		413,664
	8	77	75	.89	30.55	"			
	12	84	78	.72	30.54	"			
	4	84	80	.80	30.46	"			
	8	78	76	.89	30.50	"			
27	4	74	74	1.00	30.54	"	S'ly.		411,798
	8	78	76	.89	30.56	"			
	12	86	80	.72	30.50	"			
	4	80	78	.91	30.49	o. c.			
	8	76	75	.95	30.52	"			
28	4	74	73	.94	30.54	b. c.	S'ly.		411,798
	8	76	75	.95	30.55	"			
	12	83	77	.72	30.54	"			
	4	82	78	.80	30.49	"			
	8	77	76	.95	30.54	"			
Mar. 1	4	73	73	1.00	30.56	"	S'ly.		372,799
	8	76	75	.95	30.58	"			
	12	85	78	.68	30.53	"			
	4	80	76	.80	30.50	"			
	8	76	75	.95	30.53	b. c. l.			
2	4	74	74	1.00	30.54	b. c.	S'ly.		371,513
	8	77	75	.89	30.57	"			
	12	87	79	.65	30.53	"			
	4	82	77	.76	30.48	"			
	8	76	74	.89	30.54	b. c. l.			
3	4	73	73	1.00	30.59	b. c.	S'ly.		370,228
	8	78	74	.80	30.63	"			
	12	95	85	.60	30.57	"			
	4	84	78	.72	30.52	"			
	8	75	73	.89	30.57	"			
4	4	73	72	.94	30.60	"	S'ly.		350,487
	8	77	74	.85	30.62	"			
	12	86	77	.61	30.55	"			
	4	83	76	.68	30.50	"			
	8	75	73	.89	30.55	"			
5	4	73	72	.94	30.53	"	S'ly.		350,487
	8	78	74	.80	30.57	"			
	12	83	76	.68	30.55				
	4	83	77	.72	30.48	c.			
	8	74	73	.94	30.50	"			
6	4	72	70	.89	30.54	b. c.	S'ly.		349,258
	8	77	73	.80	30.57	"			
	12	85	76	.61	30.49	"			
	4	84	79	.76	30.43	o. c.			
	8	75	73	.89	30.49	"			
7	4	73	71	.89	30.53	b. c.	S'ly.		349,258
	8	78	74	.80	30.53	"			
	12	87	78	.61	30.47	"			
	4	85	78	.68	30.42	"			
	8	78	75	.85	30.46	o. c.			
8	4	75	74	.94	30.50	b. c.	S'ly.		349,258
	8	78	74	.80	30.51	"			
	12	85	78	.61	30.47	"			
	4	85	80	.68	30.43	o. c.			
	8	78	76	.85	30.49	"			
9	4	75	74	.94	30.52	"	S'ly.		349,258
	8	77	75	.80	30.53	"			
	12	84	78	.61	30.50	"			
	4	83	80	.85	30.45	o. c. p.			
	8	77	76	.95	30.50	o. c.			
10	4	76	75	.95	30.50	o. c. r.	S'ly.	83/100 in.	349,258
	8	77	76	.95	30.50	"			
	12	84	80	.80	30.48	o. c.			
	4	79	78	.95	30.46	b. c.			
	8	76	75	.95	30.49	"			

Table showing the meteorological observations and the average hourly volume of the Napipi River, &c.—Continued.

Date.	Hour.	Dry bulb.	Wet bulb.	Relative humidity.	Barometer.	Weather.	Wind.	Rain.	Vol.
Mar. 11	4	75	74	.94	30.53	"	S'ly.		
	8	80	76	.80	30.60	"			
	12	84	80	.80	30.55	"			
	4	81	77	.80	30.53	"			
	8	76	75	.95	30.53	"			
12	4	73	72	.94	30.54	"	S'ly.		
	8	79	76	.85	30.58	"			
	12	84	78	.72	30.52	"			
	4	79	77	.89	30.52	o. c.			
	8	76	75	.95	30.57	"			
13	4	75	74	.94	30.53	"	S'ly.		
	8	79	76	.85	30.56	"			
	12	84	79	.76	30.52	"			
	4	83	77	.72	30.42	"			
	8	76	75	.95	30.50	"			
14	4	73	73	1.00	30.53	"	S'ly.		
	8	76	75	.95	30.57	"			
	12	84	79	.76	30.54	"			
	4	76	75	.95	30.50	"			
	8	76	75	.95	30.46	"			
15	4	71	71	1.00	30.50	b. c.	S'ly.		
	8	73	72	.94	30.56	"			
	12	83	79	.80	30.44	"			
	4	84	77	.68	30.44	o. c.			
	8	76	75	.95	30.40	"			
16	4	71	71	1.00	30.50	b. c.	S'ly.		
	8	72	71	.94	30.56	"			
	12	83	77	.72	30.58	"			
	4	84	76	.65	30.44	"			
	8	74	73	.94	30.56	"			
17	4	73	72	.94	30.58	o. c.	S'ly.		
	8	74	72	.89	30.57	b. c.			
	12	85	78	.68	30.56	"			
	4	81	78	.85	30.49	o. c.			
	8	75	73	.89	30.56	"			
18	4	72	71	.94	30.56	b. c.	S'ly.		
	8	75	73	.89	30.58	o. c.			
	12	81	77	.80	30.55	"			
	4	80	77	.85	30.52	o. c. t. l. r.			
	8	73	73	1.00	30.58	"			
19	4	73	73	1.00	30.59	o. c. r.	S'ly.	$\frac{1}{100}$ in.	
	8	74	74	1.00	30.62	o. c.			
	12	...	....	......	....	"			
	4		....	......		b. c.			
	8	75	75	1.00	30.58	"			
20	4	74	74	1.00	30.62	o. c. r.	S'ly.	$\frac{31}{100}$ in.	
	8	75	75	1.00	30.62	"			
	12	78	77	.95	30.58	"			
	4	77	77	1.00	30.56	"			
	8	75	75	1.00	30.56	"			
21	4	76	75	.95	30.62	o. c.	S'ly.		
	8	78	77	.95	30.62	b. c.			
	12	83	77	.72	30.57	"			
	4	79	76	.85	30.52	"			
	8	77	76	.95	30.53	"			
22	4	73	73	1.00	30.65	o. c. r.	S'ly.	$\frac{7}{100}$ in.	
	8	75	75	1.00	30.64	"			
	12	78	78	1.00	30.63	"			
	4	79	77	.90	30.54	b. c.			
	8	77	74	.85	30.60	"			
23	4	71	71	1.00	30.63	b. c.	S'ly.		
	8	77	75	.89	30.66	"			
	12	85	76	.61	30.57	"			
	4	84	77	.68	30.51	"			
	8	79	76	.85	30.53	"			
24	4	69	68	.94	30.62	"	N'd–S'ly		
	8	78	73	.75	30.65	"			
	12	82	75	.68	30.62	"			
	4	83	77	.72	30.57	"			
	8	82	75	.68	30.52	"			
25	4	72	70	.89	30.64	"	S'ly.		
	8	74	72	.89	30.65	"			
	12	84	76	.65	30.58	"			
	4	86	78	.65	30.48	"			
	8	77	73	.85	30.53	"			

Date.	Hour.	Dry bulb.	Wet bulb.	Relative humidity.	Barometer.	Weather.	Wind.	Rain.	Vol.
Mar. 26	4	68	67	.94	30.63	"	S'ly.		361,722
	8	71	70	.94	30.58	"			
	12	86	79	.69	30.48	"			
	4	82	78	.80	30.48	"			
	8	78	72	.88	30.52	"			
27	4	70	70	1.00	30.54	"	S'ly.		342,411
	8	78	74	.80	30.57	"			
	12	86	77	.61	30.53	"			
	4	81	76	.76	30.46	"			
	8	75	73	.89	30.62	"			
28	4	73	72	.94	30.52	"	S'ly.		324,376
	8	79	74	.76	30.56	"			
	12	89	78	.55	30.45	"			
	4	81	75	.72	30.45	"			
	8	76	73	.85	30.47	"			
29	4	76	70	.70	30.50	"	S'ly.		324,376
	8	81	76	.76	30.52	"			
	12	87	77	.58	30.44	"			
	4	80	74	.72	30.43	"			
	8	72	70	.89	30.52	"			
30	4	73	71	.89	30.50	"	S'ly.		324,376
	8	77	74	.85	30.52	"			
	12	86	78	.65	30.46	"			
	4	82	76	.72	30.44	"			
	8	72	70	.89	30.50	o. c. t. l.			
31	4	72	70	.89	30.48	b. c.	S'ly.		324,376
	8	77	75	.89	30.50	"			
	12	82	78	.80	30.54	"			
	4	78	74	.80	30.51	o. c. p.			
	8	76	75	.95	30.52	o. c.			
Apr. 1	4	75	72	.84	30.46	o. c. p.	S'ly.		342,376
	8	83	77	.72	30.53	"			
	12	86	79	.68	30.52	"			
	4	80	78	.90	30.51	"			
	8	74	72	.89	30.50	"			
2	4	74	70	.79	30.53	b. c.	S'ly.		324,018
	8	77	73	.80	30.57	"			
	12	87	79	.65	30.55	"			
	4	85	78	.68	30.54	"			
	8	76	74	.89	30.50	"			
3	4	76	72	.80	30.50	"	S'ly.		306,012
	8	82	75	.68	30.52	"			
	12	88	77	.55	30.48	"			
	4	85	77	.65	30.44	o. c.			
	8	74	73	.94	30.48	"			
4	4	74	70	.79	30.49	o. c. p.	S'ly.		306,012
	8	80	73	.69	30.50	b. c.			
	12	78	77	.80	30.46	"			
	4	80	75	.76	30.45	"			
	8	77	75	.89	30.49	"			
5	4	78	75	.89	30.52	"	S'd & E'd.		306,012
	8	82	76	.72	30.54	"			
	12	89	78	.55	30.46	"			
	4	84	77	.68	30.42	"			
	8	78	75	.85	30.44	"			
6	4	76	73	.85	30.50	"	S'ly.		300,000
	8	78	74	.80	30.54	"			
	12	86	78	.65	30.50	"			
	4	83	77	.72	30.46	"			
	8	79	76	.85	30.46	"			
7	4	76	74	.89	30.51	o. c. p.	S'ly.		273,000
	8	80	76	.80	30.54	b. c.			
	12	88	79	.60	30.46	"			
	4	84	78	.72	30.44	"			
	8	77	75	.89	30.50	"			
8	4	76	74	.89	30.46	o. c.	S'ly.		258,020
	8	80	76	.80	30.51	"			
	12	85	78	.68	30.49	"			
	4	82	75	.68	30.46	"			
	8	88	76	.89	30.48	o. c. r. t. l.			
9	4	75	74	.94	30.47	o. c. r.	S'ly.	$\frac{35}{100}$ in.	242,286
	8	79	76	.85	30.53	o. c.			
	12	85	78	.68	30.46	"			
	4	81	77	.80	30.45	b. c.			
	8	77	75	.89	30.45	"			

Table showing the meteorological observations and the average hourly volume of the Napipi River, &c.—Continued.

Date.	Hour.	Dry bulb.	Wet bulb.	Relative humidity.	Barometer.	Weather.	Wind.	Rain.	Vol.
Apr. 10	4	75	74	.94	30.49	b. c.	Calm.		340,000
	8	79	75	.80	30.49	"			
	12	81	77	.80	30.47	"			
	4	81	76	.76	30.47	o. c.			
	8	77	76	.95	30.45	o. c. r. t. l.			
11	4	75	74	.94	30.51	o. c. r.	S'ly.	$1\frac{84}{100}$ in.	11,165,040
	8	76	75	.95	30.54	o. c.			
	12	79	77	.90	30.47	"			
	4	79	77	.90	30.47	b. c.			
	8	76	74	.89	30.46	"			
12	4	74	73	.96	30.52	o. c.	S'ly.		1,169,520
	8	78	76	.89	30.54	o. c.			
	12	85	78	.68	30.47	"			
	4	81	76	.76	30.47	b. c.			
	8	77	76	.95	30.46	"			
13	4	73	71	.89	30.51	b. c.	S'ly.		1,090,000
	8	77	75	.89	30.54	"			
	12	83	78	.76	30.54	"			
	4	81	76	.76	30.53	"			
	8	76	75	.95	30.50	"			
14	4	72	71	.89	30.54	o. c. r.	S'ly.	$\frac{81}{100}$ in.	2,406,570
	8	75	75	.89	30.55	o. c.			
	12	82	77	.89	30.55	"			
	4	81	77	.80	30.54	b. c.			
	8	78	76	.80	30.54	"			
15	4	76	75	.95	30.56	b. c.	S'd & W'd		3,290,000
	8	78	76	.89	30.58	"			
	12	85	79	.72	30.54	o. c. p.			
	4	80	76	.80	30.54	b. c.			
	8	76	74	.89	30.54	"			
16	4	75	75	1.00	30.63	o. c. r.	S'ly.	$3\frac{18}{100}$ in.	4,123,662
	8	78	77	.95	30.62	"			
	12	78	76	.89	30.62	"			
	4	77	76	.95	30.59	"			
	8	75	74	.94	30.60	"			
17	4	75	73	.89	30.66	b. c.	W'ly.		1,513,320
	8	77	75	.89	30.64	"			
	12	78	76	.89	30.64	o. c. r.			
	4	82	78	.80	30.58	o. c.			
	8	79	75	.80	30.60	o. c. r. t. l.			
18	4	73	73	1.00	30.64	o. c. r.	S'ly.	$\frac{58}{100}$ in.	2,190,000
	8	76	75	.95	30.64	o. c. p.			
	12	84	78	.72	30.62	"			
	4	82	78	.80	30.64	"			
	8	76	75	.95	30.62	o. c. r. t. l.			
19	4	74	73	.94	30.67	b. c.	S'ly.	$\frac{48}{100}$ in.	2,827,200
	8	76	74	.89	30.66	"			
	12	84	78	.72	30.55	"			
	4	81	77	.80	30.54	"			
	8	78	74	.80	30.56	"			
Apr. 20	4	76	73	.85	30.54	b. c.	S'd & E'd.		840,000
	8	81	76	.76	30.56	"			
	12	83	78	.76	30.50	"			
	4	82	77	.76	30.50	"			
	8	76	75	.95	30.47	"			
21	4	75	74	.94	30.56	"	S'ly.	$\frac{15}{100}$ in.	510,960
	8	78	76	.89	30.56	"			
	12	85	79	.72	30.48	"			
	4	80	77	.80	30.48	"			
	8	76	75	.95	30.49	o. c. r. t. l.			
22	4	73	72	.94	30.58	o. c.	S'ly.		480,000
	8	75	74	.94	30.60	b. c.			
	12	80	76	.80	30.60	"			
	4	80	77	.85	30.52	"			
	8	76	75	.95	30.52	o. c. r.			
23	4	75	75	1.00	30.62	"	S'd & W'd	$\frac{34}{100}$ in.	449,460
	8	77	76	.95	30.60	o. c.			
	12	80	77	.85	30.58	"			
	4	80	78	.90	30.54	"			
	8	76	75	.95	30.54	"			
24	4	75	74	.94	30.59	o. c. r.	S'ly.	$\frac{15}{100}$ in.	928,140
	8	76	75	.95	30.58	o. c. p.			
	12	82	79	.85	30.58	"			
	4	79	76	.85	30.52	"			
	8	75	74	.94	30.52	"			
25	4	74	74	1.00	30.54	o. c. r.	S'ly.	$\frac{44}{100}$ in.	790,000
	8	79	76	.85	30.50	b. c.			
	12	82	79	.85	30.58	"			
	4	79	76	.85	30.56	"			
	8	75	74	.94	30.56	"			
26	4	76	75	.95	30.60	o. c. r. t. l.	S'ly.	$\frac{1}{100}$ in.	650,000
	8	78	75	.85	30.60	b. c.			
	12	82	79	.85	30.58	"			
	4	80	77	.85	30.58	o. c. p.			
	8	78	75	.85	30.56	"			
27	4	74	73	.94	30.54	"	S'ly.	$\frac{13}{100}$ in.	508,320
	8	76	75	.95	30.60	o. c.			
	12	79	76	.85	30.60	b. c.			
	4	79	76	.85	30.62	"			
	8	75	74	.94	30.58	"			
28	4	.....	.....	.....	.....	"	S'ly.	$\frac{38}{100}$ in.	
	8	.....	.....	.....	.....	"			
	12	.....	.....	.....	.....	"			
	4	.....	.....	.....	.....	"			
	8	.....	.....	.....	.....	"			

D.

REPORT OF ASSISTANT SURGEON ERNEST NORFLEET, U. S. N.

WASHINGTON, *August* 2, 1875.

SIR: In obedience to your order, I have the honor to submit a sanitary report of the expedition engaged in the survey of the valley of the Napipi during the past winter.

The region with which the following report has to do lies wholly within the province of Choco, a small section of country situated in the northern part of the United States of Colombia, South America. It contains about eight thousand square miles, and is thus bounded: On the north, by the state of Panama and the Gulf of Darien; on the east, by the Provinces of Antioquia and Cauca; on the south, by the Province of Buenaventura; and on the west, by the Pacific Ocean.

This country is drained by the Atrato River and its tributaries; a broad and deep stream, which, taking its origin in the valley between the Cordilleras and the range of high hills skirting the Pacific, flows in a course almost due north for more than three hundred miles, and pours its waters

by many mouths into the Gulf of Darien. For the first seventy-five miles the banks are too low for cultivation, being subject to constant inundation; but above this point they are higher and very fertile, though owing to the sparseness of the population not much is cultivated. About one hundred and forty miles from its mouth the Atrato is augmented by the influx from the west of the small river Napipi, a little to the north of which passes the line of survey. From the mouth of this river to the Pacific coast the distance is nearly thirty miles, but the tortuous course of the stream more than doubles that figure.

Passing up the Napipi, the country is low and swampy till you reach a distance of ten miles when hills are met with from 50 to 100 feet high. This character of the country continues for four or five miles, and then there is an elevated table-land for about the same extent. From this point to the Pacific the country is all very hilly, and in parts almost mountainous, the elevation increasing as the ocean is neared, and reaching its highest point only a mile from the sea.

The soil, as a rule, is quite fertile; that near the Atrato is evidently the result of frequent inundation, and, like all alluvial lands, very productive.

The forests are exceedingly thick, and contain numbers of immense trees, some of which are very valuable as timber. From these trees hang innumerable creepers, and the undergrowth is so dense that in many places it is impossible to pass without cutting a trail.

The products of the country are comparatively few, though with some care and attention it would be possible to raise many more kinds of food-stuffs than are at present found in this locality. Only the banks of the rivers are cultivated, and these to a very limited extent; for little attention is required to grow the natural products of the country, and beyond this the natives do not care to exert themselves. They raise plantains, bananas, Indian corn, yams, and, I think, a little rice. They have likewise some vegetables, but mostly of the melon genus, and of little value as food. There is a dearth of fruits; oranges, cocoa-nuts, and lemons being entirely absent, and the guava and alligator-pear the only ones worthy of mention. The plantain takes the place of bread, and forms an excellent substitute; it is probably most nutritious when a little more than half ripe, and when roasted in this state makes a very palatable article of food. A healthy man will consume about six a day. The natives boil them with fish. The plant is exceedingly productive; each one bears five or six bunches a year, while each bunch contains about seventy plantains. As the trees stand only 10 or 12 feet apart, an acre will contain about four hundred, and it will readily be seen what an enormous amount of food a small portion of land may be made to yield. There is no cultivation necessary except to cut out the weeds and bushes two or three times a year. The natives are quite fond of Indian corn, but too indolent to give it the necessary attention required to produce a good crop.

The South American yam is a species of vegetable which much resembles, both in taste and appearance, our own Irish potatoe. It is cultivated in the same manner as the latter, and is prepared for the table in a variety of ways, such as boiling, frying, &c.

For meat, the natives depend chiefly on fish, which they take in nets in great numbers from the Atrato, and then cure by smoking and salting. The kind preferred is the bocachica, a very palatable fish when fresh. They have some pigs and fowls, but very few, and for the most part get what food they use of this kind from the woods, which abound in wild hogs, turkeys, ducks, quails, a species of grouse, and many other animals. Their habitations are little huts situated on the banks of the rivers, raised a few feet from the ground on piles, and made of split palms, open at two sides, and thatched with palm-leaves. Their mode of traveling is chiefly by canoes, for only here and there are found trails through the woods, by which they pass from one river to another.

The inhabitants are negroes and Indians. The former are, no doubt, the descendants of slaves who have come up the Atrato River from the eastern coast.

The men are generally well made, strong, and active, and capable of considerable fatigue, though their mode of life and desultory methods of gaining a livelihood rather unfit them for continuous labor. They soon get tired, and if separated from their families for several months become dissatisfied, and long to return home. But the Indians are much worse in the latter respect than the negroes. The negro women are not so well formed as the men, and are generally unsightly.

Owing to several causes they soon begin to decline. In the first place, they have most of the work to do, and then, too, they begin to bear children at twelve or thirteen years of age.

The ordinary attire of the men consists of a handkerchief about the loins, while the women employ a piece of cloth which fastens about the waist and falls to the knee. These people belong to the Catholic religion, and occasionally have a priest among them. They speak Spanish.

The Indians, who are probably the aborigines of this country, are not nearly so fine a race as the negroes, that is, physically. They are of low stature, have large bodies, pot-bellies, and small limbs; the head is large, and the face broad, flat, and expressionless. But they are more intelligent than the negroes, and are better acquainted with woodcraft and the country generally. Their capacity for labor is exceedingly small. They have a religion peculiar to themselves. Most of them wear tied in the hair, at the back of the head, a small image of a goat. The negroes and Indians are both very honest.

The climate is warm, moist, and enervating, though, owing to the thickness of the forests, the direct rays of the sun are seldom felt, and consequently the temperature is nearly uniform, ranging from 83° to 86° Fahr. The night is a little cooler than the day, and generally one may employ a blanket with comfort and advantage.

Two dry and two rainy seasons obtain here, but there is no period entirely exempt from rain for a length of time. The long dry season begins about the middle of December and lasts till the first or middle of April, when the rainy season sets in, bringing wet weather till August, after which comes a short dry time, followed by a wet one of the same length. The country along the Atrato River and the lower part of the Napipi is undoubtedly malarious, but as you go up into the hills the air becomes pure and salubrious. Considerable sickness prevailed in the party surveying in the former locality, while those engaged in the latter enjoyed almost uninterrupted health.

The diseases which prevail to the greatest extent are malarial fevers, consumption, pneumonia, bronchitis, diarrhœa, dysentery, and skin affections; but malaria, owing probably to acclimation, never visits the natives severely. Skin diseases among them are of several kinds, but the only trouble which affected us all, more or less, for the first few weeks in the woods and some of us all the time, was a severe form of *lichen tropicus* (prickly heat), which, from scratching and other irritation, presented in some the appearance of eczema, in others that of prurigo, but I consider it only prickly heat. This condition was no doubt due to several causes acting in concert. The sudden change from a temperate to a tropical climate, with its warmth and moisture, certainly excites the skin to greatly increased action. The contact of red flannel (which all of us wore), the want of a proper vegetable diet, and the irritation of almost constant scratching—all these are surely adequate cause for the whole trouble. The treatment for this is the application of some of the soothing anodyne washes, such as infusion of hops and camomile, acetate of lead and opium, &c., together with thorough cleanliness of body.

The only skin diseases I observed among the natives were herpes leucoderma and framboesia, or yaws. They employ no medicine for any of these, but let them take their course. They possess a few simples, which are used to purge and excite diuresis, but I could not examine into the merits of any of them.

One of the men was attacked shortly after the beginning of operations with a pustular eruption, not confined to any particular locality, but affecting the whole body more or less. He had had syphilis, I believe, though he denied it, and this may have had some influence on the malady. All the remedies the medicine-chest afforded, except mercury, were resorted to, but without success He remained in camp about two months, unable to work, and was in no better condition when we reached the ship on the 3d of May. The whole number of sick days may be summed up as follows: Malarial fevers (intermittent and remittent), 81 days; impetigo, 65 days; diarrhœa, 3 days. The treatment of fever consisted in the exhibition of quinine; the diarrhœa yielded to opium. Whole number of sick days was 149. There were twelve men in the party, which gives an average of 12.4 sick days to each man, though several were scarcely sick at all.

SANITARY PRECAUTIONS NECESSARY IN THIS CLIMATE.

Dress.—All clothing should be light and fit loosely; flannel ought always to be worn next the skin, and be changed as often as possible.

Habits.—Cleanliness is of the utmost importance, and a cold bath morning and evening will be found refreshing and beneficial. One should avoid, as far as possible, the air before sunrise as well as that after sunset, *i. e.*, remain under the tent or some cover at those times. A mosquito-bar, I fancy, protects in a slight degree from the encroachments of malaria. It is advisable to sleep under a blanket, and there are not many nights when it will be found uncomfortable.

Food.—This should be light and readily digestible. Very little meat and heating foods generally are required, and the diet should consist largely of vegetable and farinaceous articles (as far as it is possible to obtain them), among which corn-meal is entitled to a prominent place, for it is relished by every one, and seems to be peculiarly adapted to the climate; rice and plantains are both very acceptable. Condiments I do not consider necessary, except pepper and vinegar, the latter of which we felt the want of severely.

A cup of good coffee in the morning and one of chocolate (if procurable) in the evening are very grateful to the system. A little alcohol, in the form of whisky, gin, or brandy, is beneficial when returning from work in the afternoon, but should not be indulged in before that time.

I do not place much faith in the preventive powers of quinine. I regard it simply as a powerful stimulant, and I know, not only from observation, but from personal experience, that it has the effect when taken daily for a length of time of thinning the blood, destroying the appetite, and placing the system in a condition favorable to the reception of any morbid influence. A number of our party took no quinine at all, and these escaped fevers entirely, while those who used the drug regularly every day became sick, though it must be confessed that the latter were more exposed to the influence of malaria than the former, but still not to the extent, I think, that would have given rise to such a difference in sanitary condition.

Men cannot endure the same amount of fatigue in this climate that is readily borne in temperate latitudes; six or seven hours a day will be found long enough to keep them at work, and nothing will be gained by more exertion, for fatigue and then sickness will be the result. But the food undoubtedly has much to do with endurance, and the ration should be generous as regards a variety of vegetable and farinaceous articles, for those who confine themselves to this diet chiefly will be the most healthy.

Respectfully submitted.

ERNEST NORFLEET,
Assistant Surgeon, U. S. N.

Lieut. FREDK. COLLINS, U. S. N.,
Commanding Darien Survey.

E.

VOCABULARY OF THE LANGUAGE OF THE INDIANS OF THE CANTON OF CHOCO, STATE OF CAUCA, UNITED STATES OF COLOMBIA, OBTAINED BY LIEUT. FREDERICK COLLINS, U. S. N.

In collecting the words contained in the following vocabulary, I have sought to admit only such as must have existed in the language prior to the advent of the Spaniards. The names of things first brought to the knowledge of the Indians by their contact with the Spaniards are almost invariably more or less easily traced corruptions of the Spanish words. Hence they are of little or no value in tracing the relationship of this people with the other aboriginal nations.

Although most of the Indians could count readily in Spanish, I could find but one who could count beyond five in his own language, and even he could not go beyond twenty. There is no doubt that the native language is fast being supplanted by the Spanish.

In attempting to represent the pronunciation I have given to the vowels their Spanish sounds, and all the vowels are to be sounded separately. *G* is always hard except when specially noted to the contrary. *J* is strongly aspirated, and has the sound of *h* as in Spanish. *U* sounds invariably like *oo* in boot. The accents mark the syllables on which the stress is laid. In pronunciation this stress is strongly marked, and the syllables are distinctly separated, giving a disjointed, explosive

effect that is extremely harsh and disagreeable. In connection with this vocabulary the reader is referred to the remarks under head of "Inhabitants," on page 71.

One	Aba.
Two	Ŭme.
Three	Ŭmpea.
Four	Quiramáni.
Five	Juásoma (*juája*, hand).
Six	Juaquináni ába (one on the other hand).
Seven	Juaquináni úme.
Eight	Juaquináni úmpea.
Nine	Juaquináni quiramáni.
Ten	Juája eguára (both hands).
Eleven	Jénuma ába (*jénuja*, foot).
Twelve	Jénuma úme.
Thirteen	Jénuma úmpea.
Fourteen	Jénuma quiramáni.
Fifteen	Juésoma.
Sixteen	Jénu quináni ába.
Seventeen	Jénu quináni úme.
Eighteen	Jénu quináni úmpea.
Nineteen	Jénu quináni quiramáni.
Twenty	Quida (also means teeth).
Man	Umáquira.
Woman	Uéna.
Boy	Guarára.
God	Jáy (ha-ee).
Priest	Jaybaná (medicine man).
Indian	Embará.
House	Tée.
River	Dó.*
Water	Páito.
Fire	Tipú.
Road	O (sounded very long).
Mountain	Egá (soft *g*).
Dog	Usá.
Tiger	Jémamá.
Lion	Jémamá purú (*purú*, red or colored).
Head	Chimoro.
Eye	Tapú.
Nose	Cambú.
Mouth	Itái.
Ear	Cauri. (?)
Hair	Pudá.
Foot	Jenujá.
Beard	Icará.
Leg	Jénu.
Arm	Juápoto.
Hand	Juája.
Finger	Juajimíni.
Toe	Jenudrúma.

*This word is found as the termination of many of the Indian names of rivers, as *Dógua-dó*, Fish-hook river, or, perhaps, good river for fishing; *Ampúrapúra-do* (corrupted into *Amboribido*) Banana River; *Opoga-dó*, Iguana River; *Merin-do*, and others. This is frequently corrupted into *to*, as *Atrato*.

Finger-nail	Bichiví.
Thigh	Bajarápoto.
Teeth	Quída.
Rain	Cué (also the name of a river.)
Sky	Pajá.
Stars	Chintago or chintáo.
Moon	Jédéco (also means month.)
Sun	Beséa or umatáo.
Day	Pésia (*umatáo* is also used for day.)
Canoe	Jámpa or chámpa (a small canoe is called *chingo.*)
Paddle	Tobí.
Pole	Doté.
Plantain	Pata.
Banana	Taíti.
Corn	Pé.
Snake	Tamá.
Gold	Né.
Silver	Parata (probably corrupted from Spanish *plata.*)
Father	Séese.
Mother	Pápa.
Brother	Chápa.
Friend	Samambo.
Year	Cará.
Summer	Puága.
Winter	Cué (rainy season.)
Wind	Nagurrá.
Hen	Tegaré.
Cat	Mísi.
Ocean	Pusáde.
Town	Purrú.
Tree	Pacurú.
Forest	Joguá. (?)
Animal	Samó.
Fish	Betá.
Bird	Cewarrá.
Knife	Néco.
Ridge	Catúma.
To be hungry	Cachúme nicóda.
To be sleepy	Cachúme caimai.
To work	Muntrajía.
To carry	Naitúi.
To buy	Nintói.
To sell	Nintobúi.
White	Chitoró.
Black	Chipaimá.
Red	Purú.
Small	Sacé (hard *c.*)
Old	Soroá.
Good	Piachirú, bad, *cachiruchiru.*
Good-day	Piachirú cána (salutation.)
Pretty	Pïia.
Homely	Cachi irua. (Note the connection between *good* and *pretty*, *bad* and *homely.*)

Much ....Madúa.
Little ....Maäna.
High ....Wáni.
Higher ....Wawáni.
Low ....Bási.
Lower ....Wabási.
Large ....Chidrúma.
Small ....Maänachiru.

F.

LETTER FROM THE COMMISSIONER OF AGRICULTURE.

DEPARTMENT OF AGRICULTURE,
Washington, September 25, 1875.

SIR: Yours of the 20th ultimo, transmitting specimen of cotton from the Province of Choco, United States of Colombia, was duly received.

You ask my opinion as to the quality of the cotton and the probability of its proving valuable for manufacturing purposes. It is one of the many species of so-called tree-cotton to be found in various parts of tropical America, and, compared with the production of our Southern States, I do not consider it of important value.

Respectfully,

FREDK. WATTS,
Commissioner.

Lieut. FREDK. COLLINS, U. S. N.,
Navy Department, Washington, D. C.

G.

LETTER FROM THE DIRECTOR OF THE SMITHSONIAN INSTITUTION.

SMITHSONIAN INSTITUTION,
Washington, D. C., December 6, 1875.

DEAR SIR: On the return of our mineralogist recently we submitted to his examination the specimen you left with us last summer. He finds that it possesses "all the characteristics of anthracite coal," adding that "it would be hasty to infer that a deposit of anthracite may exist at the locality where this was found."

The above may be taken as entirely trustworthy.

Very truly, yours,

JOSEPH HENRY,
Director Smithsonian Institution.

Lieutenant COLLINS, U. S. N.

H.

DESCRIPTION OF SPECIMENS OF FOREST WOODS FROM THE VALLEY OF THE NAPIPI.

Number of specimen.	Native name.	Remarks.
1	Trúntago Guayacán	Dark and very heavy—fine grain—imperishable under water. The sacred wood of the ancient Chibchas. Tree large and straight. Abundant.
2	Pantáno	Dark red, resembling mahogany.
3	Costíllo	Yellowish; heavy; close grained. Tree tall and straight. Abundant.
4	Noanámo	Light colored; porous.
5	Baracóna	
6	Bémé	Black palm; variegated grain, black and white; almost as heavy and hard as iron; takes a beautiful polish; used by the natives for an endless variety of purposes.
7	Tróbli	Very light. Abundant.
8	Juáca	Whitish; heavy and close grained.
9	Bémé Cocú	Light; variegated grain.
10	Capitancíllo	Resembles black walnut. Very abundant.
11	Guigaró	Fine grain; red color.
12	Brazíl	Red dye-wood; heavy; close grained and smooth; used by natives for many purposes.
13	Carbonéro	White; fine grained; hard; a valuable wood; an excellent fire-wood.
14	Óbo Blánco	White; very light; porous; crooked.
15	Óbo Colorádo	Same as above, but has red bark.
16	Cédron	Red cedar; light; very durable in water; abundant; would make excellent piles.
17		Resembles rosewood.
18	Caimíta	Hard and close grained; very heavy.
19	Chaganá	Pinkish; heavy; fine grained.
20	Chibugá	Dark colored; coarse grained and porous.
21	Caidíta	Light and porous.
22	Taparó	White; hard; fine grained.
23	Tuáve	Yellowish; fine grained; somewhat like box-wood, but heavier.
24	Madróno	Heavy and close grained.
25	Dormillón	Resembles black walnut.
26	Choivá	Very handsome wood, resembling mahogany; extremely hard.
27	Sanca de Araña	Dark red; fine grained; handsome wood.
28	Mora	Bright yellow; a dye-wood.
29	Guína	Slightly colored; grain like black walnut.
30	Birívi	Light; crooked; porous.

Nearly all the above varieties are abundant, and almost without exception grow tall, straight, and large. Many of them woulo take a fine polish and be very valuable for ornamental work.

I.

OUTFIT.

Instruments, provisions, and stores.

INSTRUMENTS, ETC.

2 gradienters with tripods, complete.
3 leveling-rods.
1 100-foot chain, 10 pins.
1 50-foot chain, with level and adjustments.
1 100-foot tape-line.
2 hand-levels.
1 aneroid barometer, with attached thermometer.
1 aneroid barometer, compensated, graduated to 10,000 feet.
2 ivory scale thermometers.
2 ordinary Navy thermometers.
1 rain-gauge, consisting of copper cylinder, area 20 square inches, and glass vessel graduated to hundredths of inches.
1 current-meter.
2 prismatic compasses, with leather cases and slings.
6 pocket-compasses.
3 watches.

Plotting instruments.
Stationery.
Drawing-paper.
Field-books.
Blank books.
Lead pencils and rubber.
Red chalk.
Copper tacks.
3 Mackintosh bags for field-books.
2 chart-cases.
Field-maps from the surveys of 1871 and 1873.
1 boring apparatus, with tripod and tackle.
1 specimen-chest with 200 bottles.
1 cash-box.
3 gallons alcohol.

PROVISIONS, ETC.

1,000 pounds bread in half-barrels, 40 pounds each.
100 pounds rice in kegs, 25 pounds each.
1,000 pounds bacon in kegs, 30 pounds each.
340 pounds tomato soup in 2 and 4 pound cans.
280 pounds roast beef in 2 and 4 pound cans.
60 pounds roast mutton in 2 and 4 pound cans.
100 pounds pressed corned beef in 2 and 4 pound cans.
100 pounds corn-meal in tin cans, 10 pounds each.
220 pounds sugar in tin cans, 10 pounds each.
160 pounds coffee in tin cans, 15 pounds each.
14 gallons beans in tin cans, 1 gallon each.
16 pounds pickles in 1 keg.
1 dozen pickles in bottles.
4 dozen cans potted meats.
18 bottles pepper.
21 pounds table-salt in 1-pound boxes.

CAMP GEAR, ETC.

3 light fly-tents.
3 camp-chests.
2 nests camp-kettles.
3 frying-pans.
2 dozen tin pots.
2 dozen tin pans.
1 dozen iron spoons.
1 dozen knives and forks.
1 dozen sheath-knives.
½ dozen can-openers.
4 axes.
½ dozen ax-handles.
2 shovels.
2 picks.
4 hatchets.
2 hammers.
18 machetas.
2 pairs scales.
1 dozen canvas cots.

1 dozen mosquito-nets.
1 dozen woolen blankets.
1½ dozen rubber blankets.
½ dozen rubber pillows.
4 rubber bags.
Matches in tin case.
½ dozen pocket match-safes.
3 spirit cooking lamps.

CLOTHING. ETC.*

1 dozen blue denim jumpers.
1½ dozen pairs denim overalls.
1 dozen light felt hats.
1 dozen pairs canvas leggings.
41 pairs kip shoes, assorted sizes.
41 pairs woolen socks.

MISCELLANEOUS.

1 shotgun, with equipments, powder, and shot.
2 rifles, with 500 rounds fixed ammunition.
1 lead and line.

MEDICAL STORES.

1 medicine-chest with medicines.
1 case medical stores and instruments.
2 cases brandy.
2 cases gin.

Ration-table.

Day.	Bread.	Bacon.	Tomato-soup.	Beef or mutton.	Beans.	Coffee.	Sugar.
	Ounces.	*Ounces.*	*Ounces.*	*Ounces.*		*Ounces.*	*Ounces.*
First day	14	14	16	....	....	3	4
Second day	14	14	....	16	....	3	4
Third day	14	14	....	....	½ pint.	3	4

The provisions given in the foregoing list, with what could be obtained from the country, would be amply sufficient for a party of twelve men for one hundred days. As the bread is very bulky, and as plantains can always be obtained to take its place, I would recommend future explorers to take less of that article, and increase the amount of rice, which is exceedingly easy to transport and very palatable and nutritious. I would also increase the amount of corn meal, which is easily carried, and can be cooked in many ways to give variety to the ration. I would diminish the allowance of tomato-soup and increase that of beans, and replace a portion of the allowance of roast beef with some sort of a vegetable stew. Pickles were found to be a very great relish, and I would recommend a liberal allowance of them. I would also provide a liberal allowance of mustard, horse-radish, and the like, the want of which we felt greatly. In preparing the provisions for an expedition that is to be engaged in laborious work in distant regions where little can be relied upon from the country, the element of *variety* should be regarded as only less important than quantity and quality.

* Each person was required to provide himself with two complete suits of flannel underclothes.

45TH CONGRESS, 3d Session. } SENATE. { MIS. DOC. No. 16.

ESTIMATES OF THE RECEIPTS AND EXPENDITURES OF THE DISTRICT OF COLUMBIA.

LETTER

FROM

THE COMMISSIONERS OF THE DISTRICT OF COLUMBIA,

COMMUNICATING

In obedience to law, Estimates of the Receipts and Expenditures of the District of Columbia for the fiscal years ending June 30, 1879, *and June* 30, 1880.

DECEMBER 9, 1878.—Referred to the Committee on the District of Columbia, and ordered to be printed.

OFFICE OF THE COMMISSIONERS OF THE DISTRICT OF COLUMBIA,
Washington, December 6, 1878.

SIR: As required by the act of Congress, approved June 11, 1878, we transmit herewith estimates of the receipts and expenditures of the District of Columbia for the fiscal years ending June 30, 1879, and June 30, 1880, which estimates were submitted to the Secretary of the Treasury, as required by the same act, and were by him returned in the printed form in which we here transmit them.

He has approved of all the estimates except three items. The first is one of $75,000, in the estimates for 1879, for workingmen, as provided in the act approved June 20, 1878, and is correct. The act requires the District to pay one-half, and the entry of only that amount was an oversight.

The second exception taken is to the amount we estimated for the sinking-fund for the year 1880. This is a matter of grave concern, and we therefore present our views at some length. The Secretary of the Treasury refers to the estimates presented to him by the sinking-fund commissioner as if the amounts contained in them would redeem the bonds at maturity, and bases his objection to our lower estimates upon the further mistake that some definite amounts for this fund were specified in the acts authorizing the issue of the various securities. In regard to the requirements of the law in this respect we refer to the opinion of the assistant attorney for the District appended hereto. From this it appears that specific amounts are to be paid as follows:

For water-stock bonds, amounting to $423,000—$15,000 annually.
For market-stock bonds, amounting to $150,000—$15,000 annually.
Also, that a sinking-fund is required to pay off *at maturity* the following bonds:
Twenty-year funding bonds, amounting to $1,150,000.
Thirty-year funding bonds, amounting to $660,000.

To pay off these bonds respectively at maturity will require annually $54,400 and $12,250, if invested in them *at par*. The total indebtedness represented by the four classes of debt above enumerated is $2,383,000, and the total sinking-fund necessary to be drawn from the general fund to pay them at maturity is about $73,650 per annum. There remains of District debt proper $5,980,500, for which *no stated payment* to a sinking-fund is provided by law, and for part of which no provision whatever of this kind was made. As respects the 3.65 bonds, any provision that will pay them at maturity meets the conditions of their issue.

Our estimate for the sinking-fund, therefore, meets all the requirements of the contract with holders of District securities, while we think the larger and richer community that will be found here twenty or thirty years hence may well be expected to bear a fair share of the burden of expenditures of which they are to reap the benefit more even than the present generation.

To provide for payment of all the District debt at maturity of the various securities would require for the next twelve and a half years—when the $4,000,000 loan becomes due—an appropriation of about $475,000 per annum to the sinking-fund. This amount cannot be set apart with justice to other claims upon the District revenues.

We are of opinion that there is urgent need for comprehensive legislation in regard to both the District debt proper and the 3.65 bonds, and we have presented in our report a plan of relief, to which we feel justified in referring here as the best scheme we have been able to devise; but if Congress should deem it unwise to adopt that or any other similar plan for refunding the whole or part of the debt, we would then urge the expediency of permanent provision for the gradual payment of the entire District debt, all to be accomplished within the time the 3.65 bonds have yet to run. To effect this it is suggested that a fixed and constant amount be paid annually to the sinking-fund commissioner, to be by him applied to the payment of interest on all the indebtedness and to the purchase, for immediate cancellation, of the outstanding

securities of the District and the 3.65 bonds until they are all bought in and destroyed. This can be accomplished, witl the debt funded as it now is, by an annual payment, in round numbers, of $1,163,000. The Commissioners of the Distric would in this case be clothed with power to renew such of the District bonds as might be necessary in order to carry int effect this scheme, by which the old District debt would be extinguished in about twenty-five years, if payments were firs applied to it as bearing the larger rate of interest, and the 3.65 bonds at their maturity. The plan in our report, referre to above, would effect the same result, with much less annual appropriation to interest and sinking-fund.

Our estimates for the fiscal year ending June 30, 1879, embrace the sum of $281,500 to pay off bonds falling due Jan uary 1 and March 1 next, but the above plan for providing for the debt contemplates the payment of about $150,000 an the temporary renewal of the unpaid bonds. There is a loan of $40,000—represented by notes of the late Governor, bea ing 8 per cent. interest, given in the fall of 1873 and winter of 1874—made for the purpose of completing the Curtis school building in Georgetown. Our estimate of interest embraces them, and is, therefore, larger than the estimate of the sinkin fund commissioner.

We are not disposed to contest the views of the Secretary of the Treasury in respect to the supplemental estimate submitted by us for the year 1880. We have felt it a duty to present to Congress estimates of the cost of work we conside it essential to complete, if at all practicable, within the coming eighteen months. Having performed this duty, the matte is left without further comment to the wisdom of Congress.

Very respectfully,

S. L. PHELPS,
J. DENT,
W. J. TWINING, *Major of Engineers*,
Commissioners, D. (

To the PRESIDENT OF THE SENATE.

OFFICE OF THE ATTORNEY FOR THE DISTRICT OF COLUMBIA,
Washington, D. C., December 2, 1878.

GENTLEMEN: In reply to your verbal inquiry as to "the annual amounts required under existing laws to be appr priated to the sinking-fund" for the redemption of the bonds mentioned in the report of Mr. Gilfillan, Treasurer of th United States, as commissioner of the sinking-fund of the District of Columbia, I have to state:

That Mr. Gilfillan enumerates seven classes of bonds for which he thinks annual appropriations are required for sinking-fund for their redemption. Of these, two, the "Market-Stock Bonds" and the "Water-Stock Bonds," are to hav appropriated out of the receipts from the markets and from the "Water-Fund," respectively, not less than $15,000 annuall which determines definitely the amounts and the funds out of which the sinking-fund must receive the money for the redemption.

The acts authorizing the issue of the "Twenty-year 6 per cent. Funding Bonds," the "Thirty-year 6 per cent. Fundin Bonds," and the "Fifty-year 3.65 Bonds," expressly provide for the creation of a sinking-fund sufficient to pay off sai bonds *at maturity*. In the cases of the first two an *annual tax* is provided for, and a fair construction of those acts woul I think, require such an *annual* appropriation to the sinking-fund as would pay the bonds at maturity. In the case of th 3.65 bonds, "the faith of the United States is pledged * * * to provide the revenues necessary to pay the interest o said bonds as the same may become due and payable, and create a sinking-fund for the payment of the principal there at maturity." The manner in which this pledge is to be carried out is left to the discretion of Congress, which may pr vide for equal annual payments, or adapt its appropriations and the taxes to be levied upon the people of the District t the exigencies of the times, as it may deem best. Nothing, however, is left for the District but to comply with the requ sitions of the acts of Congress in the matter.

In the case of the "Permanent-improvement 6 per cent. Bonds," the act of the legislative assembly only provides f their "gradual redemption," and, in my opinion, it is optional with the District how the providing of means for redemptic shall be graduated. There is certainly nothing in the act that requires equal annual appropriations for that purpose.

I cannot exactly determine what bonds are referred to as "First issue of Permanent-improvement 7 per cent. Bonds In Mr. Gilfillan's table in regard to the sinking-fund, he speaks of them as authorized by the act of assembly of June 2 1873, but the only act of that date that authorizes the issue of bonds is Chapter III, which is supplemental to the $4,000,0 bill of July 10, 1871, and provides for the issue of not exceeding $260,000 in bonds "of the character described in said ac and in the way and manner, and subject to the limitations and restrictions provided in said act." These are therefore per cent. bonds, and are to be redeemed in the same "way and manner" as the $4,000,000 bonds.

In the table in regard to interest, Mr. Gilfillan enumerates "$670,000 Permanent-improvement 7 per cent. Bonds," authorized by the acts of the assembly of the dates of June 23 and June 25, 1873. On June 25, 1873, Chapter XIII w passed, which provides for the issue of "bonds bearing interest at the rate of 7 per cent., not to exceed the sum $530,000," and that is the only act under either of the dates named which authorizes the issue of 7 per cent. bonds. B this act says nothing whatever about redemption or a sinking-fund.

I conclude, therefore, that the "Market-Stock" and "Water-Stock" Bonds require an annual appropriation of $15,0 and out of their respective funds; that the "Twenty-year 6 per cent. Funding Bonds" and the "Thirty-year 6 per ce Funding Bonds" require such an annual appropriation as will pay them at maturity; and that the appropriations for t redemption of the other bonds referred to are left to the discretion of Congress.

Very respectfully,

FRANCIS MILLER,
Asst. Attorney, D. C.

To the COMMISSIONERS OF THE DISTRICT OF COLUMBIA.

LETTER OF THE SECRETARY OF THE TREASURY.

TREASURY DEPARTMENT,
Washington, D. C., November 29, 1878.

GENTLEMEN: I am in receipt of your estimates for the support of the Government of the District of Columbia for the fiscal years ending June 30, 1879, and June 30, 1880, which are submitted under the act of Congress of June 11, 1878, "providing a permanent form of government for the District of Columbia," requiring the Commissioners of the District of Columbia to submit to the Secretary of the Treasury, for each fiscal year, for his examination and approval, a statement showing in detail:

1. The proposed work to be undertaken by them during the fiscal year next ensuing, and the estimated cost thereof.
2. The cost of constructing, repairing, and maintaining all bridges authorized by law across the Potomac River within the District of Columbia, and also, all other streams in said District.
3. The cost of maintaining all public institutions of charity, reformatories, and prisons belonging to, or controlled wholly or in part by the District of Columbia, which are now by law supported wholly or in part by the United States or District of Columbia.
4. The expenses of the Washington aqueduct and its appurtenances.
5. An itemized statement and estimate of the amount necessary to defray the expenses of the Government of the District of Columbia for the next fiscal year.

The act requires that the Secretary of the Treasury shall carefully consider all estimates so submitted to him, and shall approve, disapprove, or suggest such changes in the same, or any item thereof, as he may think the public interest demands; and after he shall have considered and passed upon such estimates submitted to him, he shall cause to be made a statement of the amount approved by him, and the fund or purpose to which each item belongs, which statement shall be certified by him and delivered, together with the estimates as originally submitted, to the Commissioners of the District, who shall transmit the same to Congress.

This Department at present has not at its command the means to judge accurately of the amounts necessary for particular objects of expenditure, nor of the propriety or necessity of the various items for which estimates are submitted. After the law which requires accountability to the Treasury has been in operation for a few years, this Department will be in possession of the necessary data to exercise supervision of the estimates in this respect by comparison with similar expenses in former years; but in the absence of this information, I do not consider that the law requires the Secretary of the Treasury to assume the duties of an administrative officer of the District, and judge of the necessity of particular estimates. Relying upon the judgment of the Commissioners as to details, I will for the present confine myself to such approval, disapproval, or change, in particular items as will provide for all expenditures required by law, and keep the aggregate within the revenues of the District as fixed by Congress, and apply to improvements only the excess of revenue over the necessary expenditure.

I have therefore to return herewith your estimates with my approval, as follows:

FISCAL YEAR 1879.

For completion of work upon sundry avenues and streets, replacement of pavements, repairs of concrete pavements, and materials issued for permit-work, so much of the revenue of the District for the fiscal year, including an equal amount appropriated by the United States, as may remain unappropriated or unexpended, estimated at	$664,802 00
For maintaining Benning's, Anacostia, and Chain bridges, including expense for lighting, replanking Chain bridge, repairs of Benning's bridge, and embankment of Anacostia bridge, and riprap for piers and abutments of same	9,200 00
For maintaining the Washington Asylum, including salaries of commissioner, intendant, matron, physicians, clerk, and other employés, contingent expenses, and new hospital-building, $45,000; for Georgetown Almshouse, $1,800; for Hospital for the Insane, $17,000; for transportation of paupers and prisoners, $2,500; for the Reform School, $20,000; and for the relief of the poor, $15,000—in all	101,300 00
For engineering, maintenance, and general repairs of the Washington aqueduct and its appurtenances	20,000 00
For general expenses of the District of Columbia:—For salaries and contingent expenses in the offices of the commissioners, auditor and comptroller, sinking-fund, coroner, collector, attorney, treasurer, inspector of buildings, superintendent of assessments and taxes, inspector of gas and meters, assessor, harbor-master, sealer of weights and measures, and engineer, $177,306; for support of public schools, including salaries of superintendents, secretary, clerks, teachers, and janitors, for rent of school-buildings, for fuel, repairs, and contingent expenses, $380,000; for salaries of superintendents, captains, clerks, surgeons, detectives, lieutenants, sergeants, privates, station-keepers, laborers, telegraph-operators, and messengers of the Metropolitan police, including increased pay for continuous service, and for rent, fuel, repairs of station-houses, and miscellaneous items, $300,000; for salaries of commissioner, secretary, engineers, telegraph-operators, superintendent, firemen, and other employés of the fire department, and for contingent expenses, including purchase of horses and repairs to apparatus, $105,000; for salaries of judge, clerks, bailiffs, messenger, doorkeeper, and justice of the peace acting as judge of the police court, and marshal's fees, rent and contingent and judicial expenses, $18,500; for street-lights, and gas for same, repairs and erection of street-lamps, and salaries of superintendent and lamp-lighters; for removal of garbage; for salaries of superintendent and assistant, and for contingent expenses of the parking-commission; for salaries of overseer of repairs, clerk, supervisors, and for labor, and materials for repairs of streets, alleys,	

county roads, &c.; for sweeping, cleaning, and sprinkling streets and avenues, cleaning alleys and for repairs to pumps, $272,137; for miscellaneous expenditures, including salaries of market-masters and contingent expenses of markets, rent, hay-scales, advertising, and miscellaneous items, $29,439; for salaries of health-officer, inspector, clerks, pound-master, and for contingent expenses of the health department, $22,000; for interest on funded debt, $1,018,965 70; for workhouse, (appropriated for in the act of June 20, 1878,) $7,500; for refunding school and other taxes, $35,000; for workingmen, (as appropriated by the act of June 20, 1878,) $75,000; for purchasing fire-engines, $48,000; for judgments rendered against the District, $25,000; for payment of bonds falling due January 1 and March 1, 1879, $281,500—in all $2,795,347 7

This estimate, as approved, is $37,500 in excess of the amount submitted by the Commissioners, that being half o the amount appropriated by Congress by the act of June 20, 1878, for the workingmen of the District.

At the last session of Congress, the Commissioners were authorized "to issue properly-prepared bonds of the Distric of Columbia to the amount of two hundred and eighty-one thousand seven hundred and fifty dollars, for the redemption o the ten-year bonds issued by the Corporation of Washington under an act of Congress approved February twenty-seventh eighteen hundred and sixty-eight, amounting to two hundred and seventy-nine thousand two hundred and fifty dollars also, to redeem the Georgetown steam-force-pump bonds, amounting to two thousand five hundred dollars, issued unde the act of the General Assembly of June twenty-sixth, eighteen hundred and seventy-three; said bonds to be payabl thirty years after date in sums of one thousand dollars each, and bearing such rate of interest, not exceeding —— pe centum, as shall be approved by the Secretary of the Treasury."

The Commissioners thought it not expedient to advertise these bonds, and the Secretary recommends that the amoun of the debt accruing as aforesaid be paid, and held and accounted for as a part of the sinking-fund; that the five pe cent. bonds, authorized by that act, be issued to the Treasurer of the United States as a part of the sinking-fund; and that the Treasurer be authorized not only to purchase bonds due, but to purchase bonds accruing, with such funds as ma be appropriated for the sinking-fund or with the interest accruing thereon.

From this estimate the Commissioners have omitted the appropriations made by the act of June 20, 1878, for Co lumbia Hospital and Children's Hospital, on the ground that those hospitals are not such charitable institutions as th law contemplates shall be supported by the District of Columbia; but inasmuch as that act directs these appropriations t be charged against the District, they are submitted for the further consideration of Congress.

FISCAL YEAR 1880.

For the support of the government of the District of Columbia for the fiscal year ending June 30, 1880:

For completion of work upon sundry avenues and streets, replacement of pavements, repairs of concrete pavements, and materials issued for permit-work, so much of the revenue of the District for the fiscal year, including an equal amount appropriated by the United States, as may remain unappropriated or unexpended, estimated at $710,000 0

For maintaining Benning's, Anacostia, and Chain bridges, including expense for lighting, replanking Chain bridge, repairs of Benning's bridge, and embankment of Anacostia bridge, and riprap for piers and abutments of same 9,200 0

For maintaining the Washington Asylum, including salaries of commissioner, intendant, matron, physicians, clerk, and other employés, contingent expenses and new hospital-building, $45,000; for Georgetown Almshouse, $1,800; for Hospital for the Insane, $17,000; for transportation of paupers and prisoners, $2,500; for the Reform School, $20,000; and for the relief of the poor, $15,000—in all 101,300 0

For engineering, maintenance, and general repairs of the Washington aqueduct and its appurtenances ... 20,000 0

For general expenses of the District of Columbia:

For salaries and contingent expenses in the offices of the Commissioners, auditor and comptroller, sinking-fund, coroner, collector, attorney, treasurer, inspector of buildings, superintendent of assessments and taxes, inspector of gas and meters, assessor, harbor-master, sealer of weights and measures, and engineer, $163,740; for support of public schools, including salaries of superintendent, secretary, clerks, teachers, and printers, for rent of school-buildings, for fuel, repairs, and contingent expenses, $400,000; for salaries of superintendent, captains, clerks, surgeons, detectives, lieutenants, sergeants, privates, station-keepers, laborers, telegraph-operators, and messengers of the Metropolitan police, including increased pay for continuous service, and for rent, fuel, repairs of station-houses, and contingent items, $300,000; for salaries of commissioner, secretary, engineers, telegraph-operators, superintendent, firemen, and other employés of the fire department, and for contingent expenses, including purchase of horses and repairs to apparatus, $115,000; for salaries of judge, clerks, bailiffs, messenger, doorkeeper, and justice of the peace acting in absence of judge of the police court, marshal's fees, rent, and contingent and judical expenses, $18,500; for street-lights and gas for same, repairs and erection of street-lamps, for salaries of superintendent and lamp-lighters, and for removal of garbage; for salaries of superintendent and assistant, and for contingent expenses of the parking-commission; for salaries of overseer of repairs, clerk, supervisors, labor, and materials for repairs of streets, alleys, county roads, &c., for sweeping, clearing, and sprinkling the streets and avenues, cleaning alleys, and repairs to pumps, $293,455; for miscellaneous expenditures, including salaries of market-masters, and contingent expenses of markets, rent, hay-scales, advertising, and miscellaneous items, $30,375; for salaries of health-officer, inspectors, clerks, pound-master, and for contingent expenses of the health department, $22,000; for interest on funded debt, $1,016,124 12; and for sinking-fund, $256,221 25—in all 2,615,415 3

The estimate of the Commissioners for the sinking-fund is increased $56,221 25, to meet its requirements, as state by the Treasurer of the United States, who is the commissioner of this fund. The sinking-fund of the District is a par of the contract made with the creditors of the District, and should be maintained inviolate, as far as the executiv

officers are concerned. The Secretary feels that he has no right to approve an estimate for a less amount than the law requires for this purpose. If Congress should see fit to legislate upon the subject, and reduce the aggregate annual contribution to this fund in a way not to impair the credit of the District, and at the same time provide a certain specific fund which will redeem the debt of the District within a reasonable period, not to extend beyond the date of the maturity of the three-sixty-five bonds, such a proposition would have his cordial support; but, until the law is so modified, the annual appropriation to the sinking-fund should be maintained.

SUPPLEMENTAL ESTIMATE.

The Secretary, after careful consideration, is not able to approve the supplemental estimate of the Commissioners, of $1,339,886 84, for replacing the wooden pavements and for other improvements during the fiscal year ending June 30, 1880. This estimate contemplates a very extensive system of improvements, including the replacing of all the present wooden pavements of the city and the construction of auxiliary sewers, involving an expensive modification in the plan of the sewerage of a large section of the city. The greater part of this work is to supply defects in the improvements made by the Board of Public Works, which have been completed within a period of five years.

Congress has provided a very liberal fund for the support of the District by the assessment of a tax of one and one-half per cent. upon the real and personal property in the District, supplemented by license and other taxes, and by an appropriation of an equal amount from the Treasury of the United States; but in doing so has enacted that "there shall be no increase of the present amount of the total indebtedness of the District of Columbia," and has imposed severe penalties for violations of this enactment, (section 13, act June 16, 1878.)

The policy is thus clearly indicated, that under no circumstances is the debt of the District to be increased; and it would appear from the experience of the past few years that this is a safeguard which should be adhered to without qualification or condition. I cannot, by approving such an estimate, recommend to Congress the abandonment of a policy it has wisely prescribed, or permit it to be defeated by approving estimates for improvements to be made in advance of the receipt of the necessary revenue. No circumstances are stated which would justify an expenditure larger than the revenues provided, or authorize an increase of the burdens now resting upon the people of the United States, by either advancing money to, or paying a larger sum for, the government of the District than the liberal allowance made by law.

The improvements proposed are, no doubt, proper, and may be demanded by the convenience and comfort of the citizens, and would be beneficial to the city; but by extending their construction over a period of three or four years, the whole can be executed in a more judicious and economical manner than if forced into a single year. No great injury can result from this delay. Those improvements which are, for any reason, most urgently demanded, will, no doubt, be executed first, and those of a less urgent character be postponed until subsequent years.

It is believed that the streets of this city, as a general thing, are now in a better condition than the streets of any other city in the United States, and the large sum that may be annually set apart for their gradual repair will soon place them in as good condition as can be desired.

It would, therefore, seem to be neither just nor politic to require the people of the United States to assume this large expenditure for the District at a time when they are seeking to reduce all expenditures, and when appropriations for necessary objects are curtailed. On the other hand, the citizens of the District, when their burdensome special-improvement taxes are considered, feel that the present tax is as much as they should bear.

The true method for the improvement of the District, in the opinion of the Secretary, is to apply to that purpose all the annual surplus revenue available. Thus the economy exercised in other branches of expenditures will inure to the general improvement of the District.

Very respectfully,

JOHN SHERMAN,
Secretary.

To the Honorable THE COMMISSIONERS OF THE DISTRICT OF COLUMBIA.

ESTIMATES OF APPROPRIATIONS

REQUIRED FOR THE

SERVICE OF THE GOVERNMENT OF THE DISTRICT OF COLUMBIA, FOR THE FISCAL YEARS ENDING JUNE 30, 1879, AND JUNE 30, 1880, SHOWING THE APPROVAL, DISAPPROVAL, OR CHANGES SUGGESTED BY THE SECRETARY OF THE TREASURY.

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes.			Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.	Amount appropriated for the fiscal year ending June 30, 1879.
		Vol. or R. S.	Page.	Sec.			
DISTRICT OF COLUMBIA.							
FISCAL YEAR 1879.							
Improvements and Repairs—							
Completion of work upon sundry avenues and streets, (as shown in Appendix, marked "A,") $913,824 08; of which amount it is estimated that $65,781 will be required to pay for work to be completed during the fiscal year ending June 30, 1879					$65,781 00		
Replacement of pavements, 630,172.80 square yards, at $2 25 per yard, (as shown in Appendix, marked "A,") $1,418,888 80; of which amount it is estimated that $569,000 will be required to pay for work to be completed during the fiscal year ending June 30, 1879					569,000 00		
Repairs of concrete pavements					18,500 00		
Material issued for permit-work					11,521 00		
						$664,802 00	
Constructing, Repairing, and Maintaining Bridges—							
Ordinary care of Benning's, Anacostia, and Chain bridges, including fuel, oil, lamps, matches, &c	Appropriated.	19	359	1	1,200 00		
Replanking Chain bridge	Submitted				2,500 00		
Extensive repairs to Benning's bridge	do				2,500 00		
Raising embankment of Anacostia bridge, and riprapping piers and abutments	do				3,000 00		
						9,200 00	
Maintaining Institutions of Charity, Reformatories, and Prisons—							
Washington Asylum:							
One commissioner					200 00		
One intendant					800 00		
One matron					600 00		
One visiting-physician					1,200 00		
One resident-physician					480 00		
One resident-physician					360 00		
One clerk					480 00		
One baker					420 00		
Six overseers, at $600 each					3,600 00		
One watchman					300 00		
Three watchmen, at $180 each					540 00		
One driver					120 00		
One hostler					60 00		
One cook					120 00		
Two cooks, at $60 each					120 00		
Five nurses, at $60 each					300 00		
Contingent expenses, including provisions, fuel, forage, lumber, hardware, shoes, dry-goods, medicines, and miscellaneous items					33,300 00		
New hospital-building					2,000 00		
Total Washington Asylum $45,000 00							
Georgetown Almshouse, support of inmates					1,800 00		
Hospital for the Insane, board and clothing of inmates					17,000 00		
Transportation of paupers, and conveying prisoners to workhouse					2,500 00		
Reform School, support of inmates					20,000 00		
Relief of the poor					15,000 00		
						101,300 00	
Washington Aqueduct—							
Engineering, maintenance, and general repairs	Appropriated.	19	359	1		20,000 00	
GENERAL EXPENSES.							
Salaries and Contingent Expenses—							
Executive office proper:							
Two Commissioners, at $5,000 each					$10,000 00		
One secretary					2,160 00		
One clerk					1,500 00		
One clerk					1,440 00		

Estimates of appropriations—District of Columbia—for fiscal years ending June 30, 1879, *and June* 30, 1880, *&c.*—Continued.

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes. Vol. or R. S.	Page.	Sec.	Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.	Amount appropriated for the fiscal year ending June 30, 1879.
Salaries and Contingent Expenses—Continued.							
Two temporary clerks, arranging, classifying, and preserving records of former governments, at $3 each per day					$1,878 00		
One temporary clerk, arranging, classifying, and preserving records of former governments, at $1 50 per day					469 50		
One messenger					840 00		
Contingent expenses, including books, stationery, and miscellaneous items					2,712 50		
Total					21,000 00		
Auditor and Comptroller's office:							
Auditor and Comptroller					$3,000 00		
One book-keeper					1,800 00		
One clerk					1,500 00		
Three clerks, at $1,400 each					4,200 00		
One clerk					1,200 00		
Contingent expenses, including furniture, books, stationery, and miscellaneous items					860 00		
One clerk, in charge of special-assessment branch					2,160 00		
Two clerks, in special-assessment branch, at $1,200 each					2,400 00		
One clerk, in special-assessment branch, at $3 per day					940 00		
Two clerks, in special-assessment branch, at $1 50 per day					940 00		
Total					19,000 00		
Sinking-Fund office:							
Two clerks, at $1,200					$2,400 00		
Contingent expenses, including rent, printing bonds, books, &c.					1,000 00		
Total					3,400 00		
Coroner's office:							
One coroner					$1,800 00		
Contingent expenses, including stationery, jury, and witness-fees					700 00		
Total					2,500 00		
Collector's office:							
Collector					$4,000 00		
One clerk					1,700 00		
One clerk					1,200 00		
One clerk					1,000 00		
One clerk					960 00		
One clerk, at $3 per day					940 00		
One messenger					480 00		
Contingent expenses, including books, stationery, and miscellaneous items					3,320 00		
Temporary clerks, making arrearage-book					1,900 00		
Total					15,500 00		
Attorney's office:							
One attorney					$5,000 00		
One assistant attorney					1,900 00		
One special assistant attorney					960 00		
One clerk					960 00		
One clerk					192 00		
Contingent expenses, including books, stationery, and miscellaneous					988 00		
Total					10,000 00		
Treasurer's office:							
Treasurer					$2,400 00		
One clerk					1,200 00		
One messenger					900 00		
Contingent expenses, including books, stationery, car-fare, and miscellaneous items					400 00		
Total					4,900 00		

Estimates of appropriations—District of Columbia—for fiscal years ending June 30, 1879, *and June* 30, 1880, *&c.*—Continued.

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes. Vol. or R. S.	Page.	Sec.	Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.	Amount appropriated for the fiscal year ending June 30, 1879.
Salaries and Contingent Expenses—Continued.							
Inspector's of Buildings office:							
One inspector					$2,400 00		
One assistant inspector and draughtsman					1,700 00		
One assistant inspector					1,000 00		
One messenger					480 00		
Contingent expenses, including books, stationery, &c					300 00		
Total					5,880 00		
Superintendent's of Assessments and Taxes office:							
One superintendent					$2,400 00		
Two clerks, at $1,200 each					2,400 00		
One messenger					720 00		
Temporary clerks employed on numerical book					1,900 00		
Contingent expenses, including books, stationery, &c					2,000 00		
Total					9,420 00		
Inspector's of Gas and Meters office:							
One inspector					$2,000 00		
One assistant inspector					1,000 00		
Total					3,000 00		
Assessors' office:							
Three assessors, at $1,250 each					$3,750 00		
Two clerks, at $1,200 each					2,400 00		
One messenger, at $1 50 per day					469 50		
Temporary clerks employed on new assessment, and taking census					10,000 00		
Contingent expenses, including books, stationery, &c					4,380 50		
Total					21,000 00		
One harbor-master of Georgetown					$80 00		
One sealer of weights and measures					80 00		
Total					160 00		
Engineer's office:							
One chief clerk					$1,760 00		
One clerk					1,440 00		
Five clerks, (one employed for ten months,) at $1,200 each					5,900 00		
One clerk					960 00		
Two clerks, (one employed for ten months,) at $900 each					1,500 00		
Two clerks, (one employed for six months,) at $720 each					1,080 00		
One clerk, at $3 20 per day					1,001 60		
Seven clerks, (six employed for ten months,) at $3 per day each					5,616 00		
One computing-engineer					2,400 00		
One draughtsman					1,000 00		
One leveller					1,600 00		
Two levellers, at $4 per day each					2,504 00		
Two rodmen, at $780 each					1,560 00		
One axeman, at $2 per day					626 00		
One axeman					600 00		
One inspector of asphalt pavements					2,400 00		
One inspector					1,440 00		
One inspector, at $2 50 per day					882 50		
Ten inspectors, (employed for six months,) at $4 per day each					6,260 00		
Two overseers, at $1,200 each					2,400 00		
One overseer					960 00		
One overseer, at $4 per day					1,252 00		
One superintendent of property					1,800 00		
One watchman at property-yard					720 00		
Two watchmen at property-yard, (one employed for eleven months,) at $1 50 per day each					1,050 00		
One inspector of fuel, at $2 per day					626 00		
One janitor of public buildings					720 00		
Two watchmen of public buildings, at $600 each					1,200 00		
One laborer					600 00		
One laborer					480 00		
One laborer, at $1 25 per day					391 25		
One laborer, at $1 50 per day					469 50		
One superintendent of permits					1,400 00		
One sewer-tapper					1,000 00		

Estimates of appropriations—District of Columbia—for fiscal years ending June 30, 1879, *and June* 30, 1880, *&c.*—Continued.

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes. Vol. or R. S.	Page.	Sec.	Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.	Amount appropriated for the fiscal year ending June 30, 1879.
Salaries and Contingent Expenses—Continued.							
Engineer's office—*Continued.*							
Two messengers, at $600 each					$1,200 00		
One messenger					540 00		
One driver					600 00		
Contingent expenses, including books, stationery, &c					607 15		
Total					58,546 00		
Fuel, ice, repairs, general miscellaneous expenses, &c., for District offices					$3,000 00		
Total Salaries and Contingent Expenses. $177,306 00							
Public Schools of the District of Columbia—							
One superintendent					$2,700 00		
One superintendent					2,250 00		
One secretary					150 00		
One clerk to committee of accounts, Board of Trustees					150 00		
One clerk					900 00		
One clerk					800 00		
Five teachers, at $1,650 each					8,250 00		
One teacher					1,600 00		
Two teachers, at $1,350 each					2,700 00		
One teacher					1,300 00		
One teacher					1,200 00		
One teacher					1,100 00		
Fifteen teachers, at $1,000 each					15,000 00		
One teacher					960 00		
Two teachers, at $950 each					1,900 00		
Twelve teachers, at $900 each					10,800 00		
Ten teachers, at $850 each					8,500 00		
Twenty teachers, at $800 each					16,000 00		
Thirty-one teachers, at $750 each					23,250 00		
Fifty-one teachers, at $700 each					35,700 00		
Fifty-seven teachers, at $650 each					37,050 00		
Eighty-three teachers, at $600 each					49,800 00		
Twenty-five teachers, at $550 each					13,750 00		
Ten teachers, at $500 each					5,000 00		
Five teachers, at $450 each					2,250 00		
Twelve teachers, at $425 each					5,100 00		
Fifty teachers, at $400 each					20,000 00		
One temporary teacher					350 00		
Six teachers, at $250 each					1,500 00		
One janitor					1,140 00		
One janitor					1,102 00		
One janitor					1,087 00		
One janitor					922 00		
One janitor					914 00		
One janitor					900 00		
One janitor					880 00		
One janitor					850 00		
One janitor					682 00		
One janitor					622 00		
One janitor					602 00		
One janitor					588 00		
One janitor					584 00		
One janitor					582 00		
One janitor					540 00		
One janitor					430 00		
Two janitors, at $384 each					768 00		
Two janitors, at $288 each					576 00		
One janitor					250 00		
One janitor					230 00		
One janitor					225 00		
One janitor					216 00		
One janitor					192 00		
Three janitors, at $172 each					516 00		
One janitor					180 00		
One janitor					150 00		
Two janitors, at $160 each					320 00		
One janitor					140 00		
One janitor					92 23		
Six janitors, at $86 40 each					518 40		
Twelve janitors, at $80 each					960 00		
Three janitors, at $120 each					360 00		
Four janitors, at $60 each					240 00		
Eleven janitors, at $54 each					594 00		
Nine janitors, at $50 each					450 00		
Additional teachers and increase of pay by continuous service					12,000 00		
Rent of school-buildings					28,000 00		

Estimates of appropriations—District of Columbia—for fiscal years ending June 30, 1879, and June 30, 1880, &c.—Continued.

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes. Vol. or R. S.	Page.	Sec.	Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.	Amount appropriated for the fiscal year ending June 30, 1879.
Public Schools of the District of Columbia—Continued.							
Fuel					$12,000 00		
Repairs to school-buildings					20,000 00		
Contingent expenses, including books, stationery, printing, insurance, and miscellaneous items					18,587 37		
Total					380,000 00		
Metropolitan Police—							
One major and superintendent					2,560 00		
One captain					1,800 00		
One clerk					1,800 00		
One clerk					1,500 00		
Three surgeons, at $450 each					1,350 00		
Six detectives, at $1,320 each					7,920 00		
Ten lieutenants, at $1,200 each					12,000 00		
Twenty sergeants, at $1,140 each					22,800 00		
Seven acting sergeants, at $1,080 each					7,560 00		
Eighteen privates, class five, at $1,080 each					19,440 00		
Forty-three privates, class four, at $1,056 each					45,408 00		
Fifty-nine privates, class three, at $996 each					58,764 00		
Forty-one privates, class two, at $948 each					38,868 00		
Thirty-two privates, class one, at $840 each					26,880 00		
Sixteen station-keepers, at $516 each					8,256 00		
Eight laborers, at $420 each					3,360 00		
Two telegraph-operators, at $780 each					1,560 00		
One messenger					900 00		
One messenger					360 00		
One major and superintendent, mounted service					360 00		
One captain, mounted service					240 00		
Fifty lieutenants, sergeants, and privates, mounted, at $240 each					12,000 00		
Increase of pay by continuous service					3,187 00		
Rent of police station-houses and police headquarters					6,200 00		
Fuel					1,543 00		
Repairs to station-houses					1,200 00		
Miscellaneous expenses, including stationery, gas, telegraphing, ice, washing, printing, meals to prisoners, repairs to van, &c					12,184 00		
Total					$300,000 00		
Fire Department and Fire-Alarm—							
Fire Department and Alarm-Telegraph:							
Two commissioners, at $200 each					$400 00		
One commissioner and secretary					400 00		
One chief engineer					1,800 00		
One assistant engineer					1,400 00		
One superintendent of fire-alarm telegraph					1,500 00		
Two telegraph-operators, at $1,200 each					2,400 00		
Six foremen, at $1,000 each					6,000 00		
Two foremen, at $1,000 each, for six months, (new companies)					1,000 00		
Five engineers, at $1,000 each					5,000 00		
One engineer, at $1,000, for six months, (new company)					500 00		
Five firemen, at $800 each					4,000 00		
One fireman, at $800, for six months, (new company)					400 00		
One tillerman					800 00		
One tillerman, at $800, for six months, (new company)					400 00		
Six hostlers, at $800 each					4,800 00		
Two hostlers, at $800 each, for six months, (new companies)					800 00		
Thirty-six privates, at $720 each					25,920 00		
Twelve privates, at $720, for six months, (new companies)					4,320 00		
Six privates, at $720, temporarily employed					4,320 00		
Repairs to engine-houses					1,000 00		
Fuel					500 00		
Purchase of horses					2,500 00		
Repairs to apparatus					7,000 00		
Contingent expenses, including hose, forage, stationery, horseshoeing, washing, and miscellaneous items					27,840 00		
Total					105,000 00		
Courts—							
Police Court:							
One judge					$3,000 00		
One clerk					2,000 00		
One deputy clerk					1,000 00		
Two bailiffs, at $3 per day each					1,878 00		
One messenger					900 00		
One doorkeeper					540 00		

Estimates of appropriations—District of Columbia—for fiscal years ending June 30, 1879, *and June* 30, 1880, *&c.*—Continued

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes. Vol. or R. S.	Page.	Sec.	Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.	Amount appropriated for the fiscal year ending June 30, 1879.
Courts—Continued.							
One justice of the peace, acting as judge in the judge's absence					$620 00		
United States marshal's fees					2,316 00		
Rent of building for police court					1,700 00		
Contingent expenses, including books, stationery, fuel, ice, gas, witness-fees, and miscellaneous items					2,046 00		
Judicial expenses					2,500 00		
Total					18,500 00		
Streets—							
Removal of garbage					$11,796 00		
Street-lamps:							
Lighting, extinguishing, and for gas					130,630 00		
Repairs to street-lamps					1,000 00		
Erection of street-lamps					1,500 00		
Matches for use of lamp-lighters					30 00		
One superintendent					800 00		
Four lamp-lighters, at $480					1,920 00		
One lamp-lighter					120 00		
Parking Commission:							
One superintendent					900 00		
One assistant superintendent					700 00		
Contingent expenses, including laborers, cart-hire, tree-boxes, tree-straps, tree-stakes, planting and care of trees, trees, whitewashing, care of parks and trees, and miscellaneous items					13,400 00		
Current work of repair of streets, alleys, county roads, &c.:							
One overseer of repairs					2,000 00		
One clerk					1,900 00		
Four supervisors of roads, at $900 each					3,600 00		
Labor, cart-hire, materials, and miscellaneous items					56,741 00		
Sweeping, cleaning, and sprinkling streets and avenues					35,100 00		
Cleaning alleys					7,500 00		
Repairs to pumps					2,500 00		
Total					272,137 00		
Miscellaneous—							
Markets:							
One market-master					$1,650 00		
One market-master					1,500 00		
Two market-masters, at $900 each					1,800 00		
Contingent expenses, including gas, repairs, and miscellaneous items					4,550 00		
Rent of market-site and property-yards					1,175 00		
Hay-scales					200 00		
Rent of District offices					6,000 00		
General advertising					7,000 00		
Miscellaneous items, including books for register of wills, printing checks, damages, &c					5,564 00		
Total					29,439 00		
Health Department—							
One health-officer					$3,000 00		
Six sanitary inspectors, at $1,200					7,200 00		
Clerks					7,000 00		
One pound-master					1,000 00		
Contingent expenses, including books, stationery, fuel, rent, disinfectants, and miscellaneous items					3,800 00		
Total					22,000 00		
Interest on Funded Debt—							
Estimated by the Commissioners					$1,018,965 70		
Workhouse—							
Estimated by the Commissioners					7,500 00		
Refunding School and other Taxes—							
Estimated by the Commissioners					35,000 00		
Workingmen—							
Estimated by the Commissioners					37,500 00		
Purchase of Fire-Engines—							
Estimated by the Commissioners					48,000 00		

Estimates of appropriations—District of Columbia—for fiscal years ending June 30, 1879, and June 30, 1880, &c.—Continued.

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes. Vol. or R. S.	Page.	Sec.	Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.	Amount appropriated for the fiscal year ending June 30, 1879.
Judgments—							
Estimated by the Commissioners					$25,000 00		
Bonds falling Due—							
Estimated by the Commissioners					281,500 00		
Total General Expenses						$2,757,847 70	
Total Estimates, Fiscal Year 1879						3,553,149 70	
FISCAL YEAR 1880.							
Improvements and Repairs—							
Completion of work upon sundry avenues and streets, (as shown in Appendix, marked "A,") $913,824 08; of which amount it is estimated that $100,000 will be required to pay for work to be completed during the fiscal year ending June 30, 1880					100,000 00		
Replacement of pavements, 630,172.80 square yards, at $2 25 per yard, (as shown in Appendix, marked "A,") $1,418,888 80; of which amount it is estimated that $460,000 will be required to pay for work to be completed during the fiscal year ending June 30, 1880					460,000 00		
Repairs to concrete pavements					135,000 00		
Material issued for permit-work					15,000 00		
						$710,000 00	
Constructing, Repairing, and Maintaining Bridges—							
Ordinary care of Benning's, Anacostia, and Chain bridges, including fuel, oil, lamps, matches, &c	Appropriated	20	221	1	1,200 00		
Replanking and painting Chain bridge	do				2,500 00		
Repairing Benning's bridge and its carriageways	do				2,500 00		
Raising embankments of Anacostia bridge and repairing piers and abutments	do				3,000 00		
						9,200 00	
Maintaining Institutions of Charity, Reformatories, and Prisons—							
Washington Asylum:							
One commissioner					200 00		
One intendant					800 00		
One matron					600 00		
One visiting-physician					1,200 00		
One resident-physician					480 00		
One resident-physician					360 00		
One clerk					480 00		
One baker					420 00		
Six overseers, at $600 each					3,600 00		
One watchman					300 00		
Three watchmen, at $180 each					540 00		
One driver					120 00		
One hostler					60 00		
One cook					120 00		
Two cooks, at $60 each					120 00		
Five nurses, at $60 each					300 00		
Contingent expenses, including provisions, fuel, forage, lumber, hardware, shoes, dry-goods, medicines, and miscellaneous items					35,300 00		
Total Washington Asylum $45,000 00							
Georgetown Almshouse: Support of inmates					1,800 00		
Hospital for the Insane: Board and clothing of inmates					17,000 00		
Transportation of paupers and conveying prisoners to workhouse					2,500 00		
Reform School, District of Columbia: Support of inmates					20,000 00		
Relief of the poor					15,000 00		
						101,300 00	
Washington Aqueduct—							
Engineering, maintenance, and general repairs	June 20, 1878	20	221	1		20,000 00	
GENERAL EXPENSES.							
Salaries and Contingent Expenses—							
Executive office proper:							
Two Commissioners, at $5,000 each					10,000 00		
One secretary					2,160 00		
One clerk					1,500 00		
One clerk					1,440 00		

Estimates of appropriations—District of Columbia—for fiscal years ending June 30, 1879, *and June* 30, 1880, *&c.*—Continued.

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes. Vol. or R. S.	Page.	Sec.	Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.	Amount appropriated for the fiscal year ending June 30, 1879.
Salaries and Contingent Expenses—Continued.							
Executive office, proper—*Continued.*							
Two temporary clerks, arranging, classifying, and preserving records of former governments, at $3 per day each					$1,878 00		
One temporary clerk, arranging, classifying, and preserving records of former governments, at $1 50 per day					469 50		
One messenger					840 00		
Contingent expenses, including books, stationery, printing, and miscellaneous items					2,712 50		
Total					21,000 00		
Auditor and Comptroller's office:							
Auditor and Comptroller					$3,000 00		
One bookkeeper					1,800 00		
One clerk					1,500 00		
Three clerks, at $1,400					4,200 00		
One clerk					1,200 00		
Contingent expenses, including furniture, books, stationery, and miscellaneous items					860 00		
One clerk, in charge of special-assessment branch					2,160 00		
Two clerks, at $1,200 each					2,400 00		
One clerk, at $3 per day					940 00		
Two clerks, at $1 50 per day each					940 00		
Total					19,000 00		
Sinking-fund office:							
Two clerks, at $1,200					$2,400 00		
Contingent expenses					300 00		
Total					2,700 00		
Coroner's office:							
One coroner					$1,800 00		
Contingent expenses, including books, stationery, jury, and witness-fees					700 00		
Total					2,500 00		
Collector's office:							
Collector					$4,000 00		
One clerk					1,700 00		
One clerk					1,200 00		
One clerk					1,000 00		
One clerk					960 00		
One clerk, at $3 per day					940 00		
One messenger					480 00		
Contingent expenses, including books, stationery, printing, and miscellaneous items					4,720 00		
Total					15,000 00		
Attorney's office:							
One attorney					$5,000 00		
One assistant attorney					1,900 00		
One special assistant attorney					960 00		
One clerk					960 00		
One clerk					192 00		
Contingent expenses, including books, stationery, and miscellaneous items					988 00		
Total					10,000 00		
Treasurer's office:							
Treasurer					$2,400 00		
One clerk					1,200 00		
One messenger					900 00		
Contingent expenses, including books, stationery, carfare, &c					200 00		
Total					4,700 00		
Inspector's of Buildings office:							
One inspector					$2,400 00		
One assistant inspector and draughtsman					1,700 00		
One assistant inspector					1,000 00		

Estimates of appropriations—District of Columbia—for fiscal years ending June 30, 1879, and June 30, 1880, &c.—Continued.

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes. Vol. or R. S.	Page.	Sec.	Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.	Amount appropriated for the fiscal year ending June 30, 1879.
Salaries and Contingent Expenses—Continued.							
Inspector's of Buildings office—*Continued.*							
One messenger					$480 00		
Contingent expenses, including books, stationery, and miscellaneous items					300 00		
Total					5,880 00		
Superintendent's of Assessments and Taxes office:							
One superintendent					$2,400 00		
Two clerks, at $1,200					2,400 00		
One messenger					720 00		
Contingent expenses, books, stationery, and miscellaneous items					2,280 00		
Total					7,800 00		
Inspector's of Gas and Meters office:							
One inspector					$2,000 00		
One assistant inspector					1,000 00		
Total					3,000 00		
Assessor's office:							
Three assessors, at $1,250 each					$3,750 00		
Two clerks, at $1,200 each					2,400 00		
One messenger, at $1 50 per day					469 50		
Contingent expenses, including books, stationery, printing, temporary clerks, &c					4,380 50		
Total					11,000 00		
Harbor-master of Georgetown					$80 00		
Sealer of weights and measures					80 00		
Total					160 00		
Engineer's office:							
One chief clerk					$1,760 00		
One clerk					1,440 00		
Five clerks, at $1,200 each					6,000 00		
One clerk					960 00		
One clerk					900 00		
One clerk					720 00		
One clerk, at $3 20 per day					1,001 60		
Seven clerks, at $3 per day each					939 00		
One computing-engineer					2,400 00		
One draughtsman					1,000 00		
One leveller					1,600 00		
Two levellers, at $4 per day each					2,504 00		
Two rodmen, at $780 each					1,560 00		
One axeman, at $2 per day					626 00		
One axeman					600 00		
One inspector of asphalt pavements					2,400 00		
One inspector					1,440 00		
One inspector, at $2 50 per day					882 50		
Eleven inspectors, at $4 per day each, (employed for six months)					6,886 00		
Two overseers, at $1,200 each					2,400 00		
One overseer					960 00		
One overseer, at $4 per day					1,252 00		
One superintendent of property					1,800 00		
One watchman at property-yard					720 00		
Two watchmen at property-yard, at $1 50 per day each					1,095 00		
One inspector of fuel, at $2 per day					626 00		
One janitor of public buildings					720 00		
Two watchmen of public buildings, at $600 each					1,200 00		
One laborer					600 00		
One laborer					480 00		
One laborer, at $1 25 per day					391 25		
One laborer, at $1 50 per day					469 50		
One superintendent of permits					1,400 00		
One sewer-tapper					1,000 00		
Two messengers, at $600 each					1,200 00		
One messenger					540 00		
One driver					600 00		
Contingent expenses, books, stationery, &c					4,927 15		
Total					58,000 00		

Estimates of appropriations—District of Columbia—for fiscal years ending June 30, 1879, and June 30, 1880, &c.—Continued

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes. Vol. or R. S.	Page.	Sec.	Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.	Amount appropriated for the fiscal year ending June 30, 1879.
Salaries and Contingent Expenses—Continued.							
Fuel, ice, repairs, general miscellaneous expenses, &c., for District offices					$3,000 00		
Total Salaries and Expenses $163,740 00							
Public Schools of the District of Columbia—							
One superintendent					$2,700 00		
One superintendent					2,250 00		
One secretary					150 00		
One clerk to committee of accounts, board of trustees					150 00		
One clerk					900 00		
One clerk					800 00		
Five teachers, at $1,650 each					8,250 00		
One teacher					1,600 00		
Two teachers, at $1,350 each					2,700 00		
One teacher					1,300 00		
One teacher					1,200 00		
One teacher					1,100 00		
Fifteen teachers, at $1,000 each					15,000 00		
One teacher					960 00		
Two teachers, at $950 each					1,900 00		
Twelve teachers, at $900 each					10,800 00		
Ten teachers, at $850 each					8,500 00		
Twenty teachers, at $800 each					16,000 00		
Thirty-one teachers, at $750 each					23,250 00		
Fifty-one teachers, at $700 each					35,700 00		
Fifty-seven teachers, at $650 each					37,050 00		
Eighty-three teachers, at $600 each					49,800 00		
Twenty-five teachers, at $550 each					13,750 00		
Ten teachers, at $500 each					5,000 00		
Five teachers, at $450 each					2,250 00		
Twelve teachers, at $425 each					5,100 00		
Fifty teachers, at 400 each					20,000 00		
One temporary teacher					350 00		
Six teachers, at $250 each					1,500 00		
One janitor					1,140 00		
One janitor					1,102 00		
One janitor					1,087 00		
One janitor					922 00		
One janitor					914 00		
One janitor					900 00		
One janitor					880 00		
One janitor					850 00		
One janitor					682 00		
One janitor					622 00		
One janitor					602 00		
One janitor					588 00		
One janitor					584 00		
One janitor					582 00		
One janitor					540 00		
One janitor					430 00		
Two janitors, at $384 each					768 00		
Two janitors, at $288 each					576 00		
One janitor					250 00		
One janitor					230 00		
One janitor					225 00		
One janitor					216 00		
One janitor					192 00		
Three janitors, at $172 each					516 00		
One janitor					180 00		
One janitor					150 00		
Two janitors, at $160 each					320 00		
One janitor					140 00		
One janitor					92 23		
Six janitors, at $86 40 each					518 40		
Twelve janitors, at $80 each					960 00		
Three janitors, at $120 each					360 00		
Four janitors, at $60 each					240 00		
Eleven janitors, at $54 each					594 00		
Nine janitors, at $50 each					450 00		
Additional teachers and increase of pay by continuous service					22,000 00		
Rent of school-buildings					30,000 00		
Fuel					12,000 00		
Repairs to school-buildings					25,000 00		
Contingent expenses, including books, stationery, printing, insurance, and miscellaneous items					21,587 37		
Total					400,000 00		

Estimates of appropriations—District of Columbia—for fiscal years ending June 30, 1879, and June 30, 1880, &c.—Continued.

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes. Vol. or R. S.	Page.	Sec.	Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.	Amount appropriated for the fiscal year ending June 30, 1879.
Metropolitan Police—							
One major and superintendent					$2,560 00		
One captain					1,800 00		
One clerk					1,800 00		
One clerk					1,500 00		
Three surgeons, at $450 each					1,350 00		
Six detectives, at $1,320 each					7,920 00		
Ten lieutenants, at $1,200 each					12,000 00		
Twenty sergeants, at $1,140 each					22,800 00		
Seven acting sergeants, at $1,080 each					7,560 00		
Eighteen privates, class five, at $1,080 each					19,440 00		
Forty-three privates, class four, at $1,056 each					45,408 00		
Fifty-nine privates, class three, at $996 each					58,764 00		
Forty-one privates, class two, at $948 each					38,868 00		
Thirty-two privates, class one, at $840 each					26,880 00		
Sixteen station-keepers, at $516 each					8,256 00		
Eight laborers, at $420 each					3,360 00		
Two telegraph-operators, at $780 each					1,560 00		
One messenger					900 00		
One messenger					360 00		
One major and superintendent, mounted service					360 00		
One captain, mounted service					240 00		
Fifty lieutenants, sergeants, and privates, mounted, at $240 each					12,000 00		
Increase of pay by continuous service					3,187 00		
Rent of police station-houses and police headquarters					6,200 00		
Fuel					1,543 00		
Repairs to station-houses					1,200 00		
Miscellaneous expenses, including stationery, gas, telegraphing, ice, washing, printing, meals to prisoners, repairs to van, &c					12,184 00		
Total					300,000 00		
Fire Department and Fire-Alarm—							
Two commissioners, at $200 each					$400 00		
One commissioner and secretary					400 00		
One chief engineer					1,800 00		
One assistant engineer					1,400 00		
One superintendent of fire-alarm telegraph					1,500 00		
Two telegraph-operators, at $1,200 each					2,400 00		
Eight foremen, at $1,000 each					8,000 00		
Six engineers, at $1,000 each					6,000 00		
Six firemen, at $800 each					4,800 00		
Two tillermen, at $800 each					1,600 00		
Eight hostlers, at $800 each					6,400 00		
Forty-eight privates, at $720 each					34,560 00		
Six privates, at $720 each, temporarily employed					4,320 00		
Repairs to engine-houses					1,000 00		
Fuel					500 00		
Purchase of horses					2,500 00		
Repairs to apparatus					7,000 00		
Contingent expenses, including hose, forage, stationery, horseshoeing, washing, and miscellaneous items					30,420 00		
Total					115,000 00		
Courts—							
Police court:							
One judge					$3,000 00		
One clerk					2,000 00		
One deputy clerk					1,000 00		
Two bailiffs, at $3 per day					1,878 00		
One messenger					900 00		
One doorkeeper					540 00		
One justice of the peace, acting as judge in judge's absence					620 00		
United States marshal's fees					2,316 00		
Rent of building for police court					1,700 00		
Contingent expenses, including books, stationery, fuel, ice, gas, witness-fees, and miscellaneous items					2,046 00		
Judicial expenses					2,500 00		
Total					18,500 00		
Streets—							
Removal of garbage					$10,355 00		
Street lamps:							
Lighting, extinguishing, and gas					134,630 00		
Repairs to street-lamps					1,000 00		
Erection of street-lamps					1,500 00		
Matches for use of lamp-lighters					30 00		

Estimates of appropriations—District of Columbia—for fiscal years ending June 30, 1879, *and June* 30, 1880, *&c.*—Continued

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes. Vol. or R. S.	Page.	Sec.	Estimated am't required for service of year ending June 30, 1880.	Estimated amount required for service of year ending June 30, 1879.	Amount appropriated for the fiscal year ended June 30, 1878.
Streets—Continued.							
Street lamps—*Continued.*							
One superintendent					$800 00		
Four lamp-lighters, at $480 each					1,920 00		
One lamp-lighter					120 00		
Parking-commission:							
One superintendent					900 00		
One assistant superintendent					700 00		
Contingent expenses, including laborers, cart-hire, trees, tree-boxes, tree-straps, tree-stakes, planting and care of trees, whitewashing, care of parks, and miscellaneous items					13,400 00		
Current work of repairs of streets, alleys, county roads, &c.:							
One overseer of repairs					2,000 00		
One clerk					1,900 00		
Four supervisors of roads, at $900 each					3,600 00		
Labor, cart-hire, materials, and miscellaneous items					75,500 00		
Sweeping, cleaning, and sprinkling streets and avenues					35,100 00		
Cleaning alleys					7,500 00		
Repairs to pumps					2,500 00		
Total					293,455 00		
Miscellaneous—							
Markets:							
One market-master					$1,650 00		
One market-master					1,500 00		
Two market-masters					1,800 00		
Contingent expenses, including gas, repairs, and miscellaneous items					4,550 00		
Rent of market-site and property-yards					1,175 00		
Hay-scales					200 00		
Rent of district offices					6,000 00		
General advertising					7,000 00		
Miscellaneous items: Books to register of wills, printing checks, damages, &c					6,500 00		
Total					30,375 00		
Health Department—							
One health-officer					$3,000 00		
Six sanitary inspectors, at $1,200					7,200 00		
Clerks					7,000 00		
One pound-master					1,000 00		
Contingent expenses, including books, stationery, fuel, rent, disinfectants, and miscellaneous items					3,800 00		
Total					22,000 00		
Interest on Funded Debt—							
Estimated by the Commisioners					$1,016,124 12		
Sinking-Fund—							
Estimated by the Commissioners					$200,000 00		
Total General Expenses						$2,559,194 12	
NOTE.—The Treasurer of the United States, as commissioner of the sinking-fund of the District of Columbia, estimates for the two preceding items as follows: Interest on funded debt ... $1,012,924 12 Sinking-fund ... 271,221 25 Total ... 1,284,145 37 See details in Appendix, marked "B."							
Total Estimates, Fiscal Year 1880						3,399,694 12	
SUPPLEMENTAL ESTIMATES, FISCAL YEAR 1880.							
Improvements and Repairs—							
Replacing wooden pavements						$676,886 84	
Replacing blue-stone pavements						50,000 00	
Additional work of improvements						200,000 00	
Auxiliary sewers						413,000 00	
Total Supplemental Estimates, Fiscal Year 1880						1,339,886 84	

APPENDIX.

APPENDIX A.

Explanation of the estimates of the Commissioners of the District of Columbia for the fiscal years ending June 30, 1879, *and June* 30, 1880.

OFFICE OF THE COMMISSIONERS OF THE DISTRICT OF COLUMBIA,
Washington, November 15, 1878.

SIR: We have the honor to submit estimates for expenditures of the District of Columbia for the fiscal year ending June 30, 1879, under the following five heads, as prescribed in the act approved June 11, 1878, entitled "An act providing a permanent form of government for the District of Columbia:"

First....Proposed work of improvement and repair	$664,802 00
Second..Constructing, repairing, and maintaining bridges	9,200 00
Third....Maintaining institutions of charity, reformatories, and prisons	101,300 00
Fourth..Expenses of Washington aqueduct and appurtenances	20,000 00
Fifth....Expenses of the government of the District of Columbia	2,757,847 70
Total	3,553,149 70

For more detailed statements, see accompanying estimates of expenditures and receipts, and engineer's tables Nos. 5 and 6, relating to work of improvement and repairs; but those two tables include the work of improvement and repairs proposed to be done both for the current fiscal year, as estimated above, and for the fiscal year ending June 30, 1880.

By order of the Board:

S. L. PHELPS, *President.*

Hon. JOHN SHERMAN,
Secretary of the Treasury.

Estimated expenditures for the fiscal year ending June 30, 1879, *under the five heads enumerated in the act of Congress approved June* 11, 1878, *providing a permanent form of government for the District of Columbia.*

First....Expenditures for improvements and repairs	$65,781 00
Replacement of pavements	569,000 00
Repairs of concrete pavements	18,500 00
Material issued for permit-work	11,521 00
Total	664,802 00
Second..Constructing, repairing, and maintaining bridges within the District of Columbia, as per estimate of Colonel T. L. Casey, United States Engineers, in charge. Total	$9,200 00
Third...Maintaining institutions of charity, reformatories, and prisons:	
Washington Asylum	$45,000 00
Georgetown Almshouse	1,800 00
Hospital for the Insane	17,000 00
Transportation of paupers, and conveying prisoners to workhouse	2,500 00
Reform School	20,000 00
Relief of the poor	15,000 00
Total	101,300 00
Fourth..Washington aqueduct and appurtenances:	
Maintenance and general repairs, as per estimate of Colonel T. L. Casey, U. S. Engineers, in charge. Total	$20,000 00
Fifth...General expenses of the government of the District of Columbia:	
Salaries and contingent expenses	$177,306 00
Public schools	380,000 00
Metropolitan police	300,000 00
Fire department and alarm-telegraph	105,000 00
Courts	18,500 00
Streets	272,137 00
Health department	22,000 00
Debt—Interest	1,018,965 70

Fifth ...General expenses of the government of the District of Columbia—*Continued.*

Miscellaneous	$29,439 0
Workhouse	7,500 0
Refunds	35,000 0
Workingmen	37,500 0
Purchase of fire-engines	48,000 0
Judgments	25,000 0
Bonds falling due	281,500 0
Total	2,757,847 7

Estimated receipts from taxes, and revenues of the District, other than appropriations, for the fiscal year ending June 30, 1879			$1,777,174 0
Appropriations for the general expenses of the District of Columbia by act approved June 20, 1878		$1,250,000 00	
Deduct payments made as required in the appropriation, and *not* provided for in the act approved June 11, 1878, as part of the expenditures to be equally borne by the United States and the District of Columbia, as follows: On account of—			
Columbia Hospital for Women	$12,000 00		
Children's Hospital	5,000 00		
Children's Hospital	10,000 00		
St. Ann's Infant Asylum	5,000 00		
Industrial Home School	5,000 00		
National Association for Relief of Colored Women, &c	5,000 00		
		42,000 00	
Amount remaining to the credit of the United States as its proportion of the expenses of the District of Columbia for the fiscal year ending June 30, 1879, under the act approved June 11, 1878			1,208,000 0
Total estimated receipts and appropriations			2,985,174 0
Estimated receipts from taxation		$1,777,174 00	
Appropriated by the United States, as above		1,208,000 00	
Amount due from the United States, on basis of payment of 50 per cent. of expenses of District			569,174 0
Total estimated revenue, including deficiency in the appropriation by Congress			3,554,348 0

OFFICE OF THE COMMISSIONERS OF THE DISTRICT OF COLUMBIA,
Washington, November 15, 1878.

SIR: We have the honor to submit estimates for expenditures of the District of Columbia for the fiscal year endin June 30, 1880, under the following five heads, as prescribed in the act approved June 11, 1878, entitled "An act providin a permanent form of government for the District of Columbia:

First	Proposed work of improvement and repair	$710,000 (
Second	Constructing, repairing, and maintaining bridges	9,200 (
Third	Maintaining institutions of charity, reformatories, and prisons	101,300 (
Fourth	Expenses of Washington aqueduct and appertenances	20,000 (
Fifth	Expenses of the government of the District of Columbia	2,559,194
	Total	$3,399,694

For more detailed statements, see accompanying estimates of expenditures and receipts, and engineer's tables N 5 and 6, relating to work of improvement and repairs, also referred to in our letter of this date, transmitting estimates f the fiscal year ending June 30, 1879; but, we repeat, those two tables include work of improvement and repairs propos to be done both for the current fiscal year, as estimated above, and for the fiscal year ending June 30, 1879.

We submit a supplemental estimate of expenditures for this year, *i. e.*, 1880, independent of our regular estimate excess of estimated receipts for the same period by $1,339,886 84, which excess is due to the large amount of work sewers and street pavements imperatively required, the cost of which we do not feel justified in omitting from our estimat which for the two fiscal years (ending June 30, 1879–'80) together embrace the outlay necessary to replace all rotten-wo pavements in the two cities in the District; to build the auxiliary sewers necessary to prevent overflow in them, and lieve over-taxed sewers; to resurface concrete pavements now badly worn, and, in addition, to expend $200,000 for n improvements, as much needed as any of the other work.

By order of the Board:

S. L. PHELPS, *President.*

HON. JOHN SHERMAN,
Secretary of the Treasury.

Estimated expenditures for the fiscal year ending June 30, 1880, *under the five heads enumerated in the act of Congress, approved June* 11, 1878, *providing a permanent form of government for the District of Columbia.*

First....Improvement and repairs	$100,000 00
Replacement of pavements	460,000 00
Repairs to concrete pavements	135,000 00
Material issued for permit-work	15,000 00
Total	710,000 00
Second..Constructing, repairing, and maintaining bridges within the District of Columbia, across the Potomac river and other streams, as per estimate of Col. T. L. Casey, United States Engineer in charge	$9,200 00
Third...Maintaining institutions of charity, reformatories, and prisons:	
Washington Asylum	$45,000 00
Georgetown Almshouse	1,800 00
Hospital for the Insane	17,000 00
Transportation of paupers, and conveying prisoners to the workhouse	2,500 00
Reform School	20,000 00
Relief of the poor	15,000 00
Total	101,300 00
Fourth..Washington aqueduct and appurtenances:	
Engineering, maintenance, and general repairs, as per estimate of Col. T. L. Casey, United States Engineers, in charge	$20,000 00
Fifth....General expenses of the government of the District of Columbia:	
Salaries and contingent expenses	$163,740 00
Public schools	400,000 00
Metropolitan police	300,000 00
Fire department and alarm-telegraph	115,000 00
Courts	18,500 00
Streets	293,455 00
Health department	22,000 00
Debt—Interest	1,016,124 12
Sinking-fund	200,000 00
Miscellaneous	30,375 00
Total	2,559,194 12
Estimated receipts from taxes and revenues of the District of Columbia, other than appropriations, for the fiscal year ending June 30, 1880	$1,700,000 00
Assumed appropriation by the United States	1,700,000 00
Total estimated receipts from both sources	3,400,000 00

Supplemental estimate of expenditures for the fiscal year ending June 30, 1880, *under the first head enumerated in the act of Congress approved June* 11, 1878, *providing a permanent form of government for the District of Columbia.*

Replacing wooden pavements	$676,886 84
Replacing blue-stone pavements	50,000 00
Additional work of improvements	200,000 00
Auxiliary sewers	413,000 00
Total	1,339,886 84

TABLE No. 5.—*Schedule of Streets paved with wood and now requiring repair.*

Street.	Limits.	No. of square yards.	Remarks.
1st Street, East	From B St., South, to C St., South	2,093.32	Rectangular block; in bad condition.
1st Street, East	From B St., North, to C St., North	2,125.13	Rectangular block; in bad condition.
1st Street, West	From Maryland Ave. to I St., North	13,120.56	Rectangular block, from Maryland Avenue to Pennsylvania Avenue, in fair condition; Pennsylvania Avenue to I Street, in bad condition.
2d Street, East	From East Capitol St. to B St., North	2,365.79	Round block; requires repairing.
2d Street, East	From East Capitol St. to D St., South	7,867.32	Round block; requires but slight repairs.
2d Street, West	From B St., South, to Maryland Ave	1,109.95	Round block; in good condition.
2d Street, West	Penn. Ave., between I and K Sts., South	15,125.76	Rectangular block; in bad condition.
3d Street, West	From B St., South, to L St., North	10,460.81	Round block—B Street to north curb-line of the Mall, in fair condition; from N. C. L. Mall to S. B. L. (Missouri Avenue) in bad condition; from S. B. L. (Missouri Avenue) to N. B. L. (Pennsylvania Avenue) requires slight repairs; Pennsylvania Avenue to L Street, North, in bad condition.
4th Street, East	From East Capitol St. to C St., South	1,499.39	Rectangular block; in bad condition, (south of Pennsylvania Avenue.)
4th Street, East	From East Capitol St. to C St., South	3,836.29	Round block; requires slight repairs.
5th Street, East	From East Capitol St. to C St., South	5,519.18	Rectangular block; requires slight repairs.
5th Street, West	From L St., North, to O St., North	5,087.39	Rectangular block; in bad condition.
6th Street, East	From North Carolina Ave. to Pa. Ave	1,000.56	Rectangular block; in bad condition.
6th Street, West	From F St., North, to Boundary	16,742.73	Rectangular block; in bad condition.
7th Street, East	From Pennsylvania Ave. to D St., South	948.73	Rectangular block; in bad condition.
7th Street, West	From C St., North, to D St., North	511.05	Rectangular block; in bad condition, (west side railroad track.)
7th Street	Intersection 7th St., West, C St., Louisiana Ave., and Pennsylvania Avenue.	2,708.72	Rectangular block; in bad condition.
7th Street, West	From L St., South, to Potomac Ferry	3,681.78	Rectangular block; in bad condition.
8th Street, East	From D St., South, to Pennsylvania Ave.	4,082.97	Rectangular block; in bad condition.
8th Street, West	From C St., North, to E St., North	15,473.14	Rectangular block; from G Street to H Street, in good condition; remainder in bad condition.
8th Street, West	From G St., North, to R St., North		
9th Street, West	From B St., North, to Pennsylvania Ave.	13,192.50	Rectangular block; in bad condition.
9th Street, West	From Q St., North, to U St., North		
10th Street, West	From F St., North, to G St., North	13,700.06	Rectangular block; in bad condition.
10th Street, West	From K St., North, to R St., North		
11th Street, West	From K St., North, to O St., North	6,495.02	Rectangular block; in bad condition.
11th Street, West	From G St., North, to F St., North		
12th Street, West	From N St., North, to P St., North	3,048.19	Rectangular block; in bad condition.
14th Street, West	From Boundary to Circle	16,094.64	Rectangular block; in bad condition, (west side of 14th St.
15th Street, West	From B St., North, to Pennsylvania Ave.	19,394.77	Rectangular block; in bad condition.
15th Street, West	From K St., North, to W St., North		
16th Street, West	From H St., North, to Boundary	36,589.75	Rectangular block; in bad condition.
18th Street, West	From L St., North, running South	6,830.43	Rectangular block; in bad condition.
19th Street, West	From Pennsylvania Ave. to Circle	11,396.04	Rectangular block; in bad condition.
20th Street, West	From Pennsylvania Ave. to K St., North	2,270.00	Rectangular block; in bad condition.
21st Street, West	From Pennsylvania Ave. to K St., North	1,325.28	Rectangular block; in bad condition.
22d Street, West	From K St., North, to L St., North	3,358.25	Rectangular block; in bad condition.
22d Street, West	From New Hampshire Ave. to M St., North		
23d Street, West	From Circle to M St., North	2,499.44	Round block; in bad condition.
26th Street, West	From Pennsylvania Ave. to L St., North	1,383.82	Rectangular block; in bad condition.
A Street, South	From 1st St., East, to 3d St., East	1,896.83	Round block; requires slight repairs.
A Street, North	From 1st St., East, to 3d St., East	2,489.48	Rectangular block; in bad condition.
A Street, North	From 14th St., East, to 2d St., East	2,526.52	Rectangular block; in bad condition.
B Street, South	From 6th St., West, to 14th St., West	13,001.03	Rectangular block; in bad condition.
B Street, South	From 1st St., West, to Maryland Ave	5,416.03	Round block; in excellent condition.
B Street, South	From Pennsylvania Ave. to 5th St., East.	3,789.14	2,485.70 square yards, round block, between Pennsylvania Avenue and 4th Street, East, requires but slight repair; 1,303.44 square yards, rectangular block, between 4th and 5th Streets, in bad condition.
B Street, North	From 1st St., West, to 3d St., West	3,364.82	Rectangular block; in bad condition.
C Street, North	From 2d St., West, to 4½ St., West	3,904.48	Round block; requires slight repairs.
C Street, North	From 1st St., West, to North Capitol St.	4,026.04	Rectangular block; in bad condition.
C Street, North, (Market Space)	From 7th St., West, to 8th St., West	1,167.38	Rectangular block; in bad condition.
C Street, North	From North Capitol St. to 3d St., East	7,897.99	Rectangular block; in bad condition.
C Street, South	From 4th St., East, to Pennsylvania Ave.	1,865.95	Rectangular block; requires repairing, (south side of the space.)
C Street, North	From Pennsylvania Ave. to 6th St., West.	1,633.33	Rectangular block; requires repairing, (north side of the space.)
D Street, South	From 7th St., East, to 8th St., East	1,369.00	Rectangular block; north side space front Wallach's School-house.
D Street, North	From 14th St., West, to 15th St., West	1,934.22	Rectangular block; in bad condition.
E Street, North	From 4th St., West, to New Jersey Ave	3,864.81	Rectangular block; in bad condition.
E Street, North	From 14th St., West, to 15th St., West	1,958.05	Rectangular block; all in bad condition.
East Capitol Street	From 2d St., East, to 11th St., East	10,893.09	Rectangular block; in bad condition.
F Street, North	From New Jersey Ave. to 4th St., West	4,171.97	Rectangular block; in bad condition.
F Street, North	From 17th St., West, to 18th St., West	2,579.12	Rectangular block; requires slight repairs.
H Street, North	From 3d St., West, to 4th St., West	9,740.06	Rectangular round block; in bad condition.
H Street, North	From North Capitol St. to 1st St., East	4,194.08	Round block; in bad condition.
I Street, North	From 5th St., West, to 10th St., West	4,968.70	Rectangular block; in bad condition.
K Street, North	From 18th St., West, to Penn. Ave. Circle	12,271.84	Rectangular block; in bad condition.
L Street, North	From 6th St., West, running West	11,197.88	Rectangular block; in bad condition.
M Street, North	From New Jersey Ave. to 26th St., West.	18,702.70	Rectangular block; in bad condition.
M Street, North	From New Jersey Ave. to 26th St., West	8,313.29	Round block; in bad condition.
N Street, North	From 5th St., West, to Scott Square	14,890.57	Rectangular block; in bad condition.

TABLE NO. 5.—*Schedule of Streets paved with wood and now requiring repair*—Continued.

Street.	Limits.	No. of square yards.	Remarks.
O Street, North	From 16th St., West, to 17th St., West	1,764.49	Rectangular block; in bad condition.
P Street, North	From New Jersey Ave. to 18th St., West	24,994.63	Round block; from New Jersey Avenue to 7th Street requires slight repairs; 7th to 14th, in bad condition; 14th to 18th, requires slight repairs.
R Street, North	From 9th St., West, to 14th St., West	8,404.90	Round block; in bad condition.
Delaware Avenue	From B St., North, to C St., North	2,154.56	Rectangular block; in bad condition.
Louisiana Avenue	From 6th St., West, to 7th St., West	3,509.44	Rectangular block; in bad condition.
Maryland Avenue	From 1st St., West, to 3d St., West	3,513.12	Round block; in good condition.
Massachusetts Avenue	From New Jersey Ave. to 13th St., West	22,204.79	Rectangular block; in bad condition.
Missouri Avenue	From 3d St., West, to 4½ St., West	2,591.92	Round block; requires slight repairs.
New Hampshire Avenue	From Q St., North, to Pennsylvania Ave	17,952.76	Rectangular block; in bad condition.
North Carolina Avenue	From 4th St., East, to 6th St., East	2,183.38	Rectangular block; in bad condition.
New Jersey Avenue	From D St., North, to O St., North	37,221.94	Rectangular block; in bad condition.
New Jersey Avenue	From B St., South, to E St., South	8,919.24	Rectangular block; in bad condition.
Pennsylvania Avenue	From 7th St., East, to 2d St., East	10,565.16	Rectangular block; in bad condition.
Pennsylvania Avenue	From 23d St., West, to 26th St., West	5,157.15	Rectangular block; in bad condition, (south side.)
Rhode Island Avenue	From 5th St., West, to 17th St., West	25,160.00	Rectangular block; in bad condition.
South Carolina Avenue	From 7th Street, East, to 8th Street, East	790.23	Rectangular block; in bad condition.
GEORGETOWN.			
1st Street	From High Street to Fayette Street	5,625.30	Rectangular block; in bad condition.
2d Street	From High Street to Fayette Street	4,297.72	Rectangular block; in bad condition.
Congress Street	From West Street to Bridge Street	4,862.88	Rectangular block; in bad condition.
Gay Street	From Montgomery Street to High Street	5,820.62	Square and round blocks; in bad condition.
Greene Street	From West Street to Bridge Street	4,950.36	Round block; in bad condition.
Market Street	From First Street to Third Street	2,113.47	Round block; in bad condition.
Potomac Street	From Bridge Street to Second Street	2,964.67	Rectangular block; in bad condition.
Washington Street	From Bridge Street to Gay Street	1,921.67	Rectangular block; in bad condition.
West Street	From Washington Street to High Street	3,561.24	Rectangular block; in bad condition.
		630,172.80	

TABLE NO. 6.—*Schedule of Proposed Improvements for Completion of sundry Avenues and Streets in the Cities of Washington and Georgetown, D. C.*

Street or Avenue.	Limits.	Proposed improvement.	Estimated cost.
Canal	B Street to M Street, South	Grade the entire width of street	$84,145 60
New Jersey Avenue	I Street to M Street, South	Grade, gravel, and sidewalks, and continuation of main sewer.	19,955 46
South Capitol Street	B Street to S Street, South	Grade, gravel, and sidewalk	29,333 65
North Capitol Street	K Street to Boundary, North	Grade, gravel, and sidewalk	12,452 40
M Street, North	New York Avenue to 1st Street, East	Grade, gravel, and sidewalk	12,146 52
Boundary Street, North	6th Street, West, to 2d Street, East	Grade, gravel roadway, and sidewalk on south side	12,729 60
1st Street, East	K Street to New York Avenue, North	Grade, fill over six-foot sewer to Boundary Street	10,900 00
Delaware Avenue	H Street to M Street, North	Grade	6,208 74
G Street, North	North Capitol Street to 5th Street, East	Grade, and sidewalks, between North Capitol Street and Delaware Avenue.	5,511 66
D Street, North	Delaware Avenue to 2d Street, East	Grade, gravel, and sidewalks	6,023 50
Beall Street, Georgetown	High Street to Monroe Street	Gravel, and gutters	2,154 60
Dunbarton St., Georgetown	Congress Street to Washington Street	Grade, gravel, and sidewalks	2,608 20
Pennsylvania Avenue	1st Street to 15th Street	Relay sidewalks	14,841 00
I Street	North Capitol Street to 1st Street, East	Relay sidewalks	397 95
10th Street, West	B Street to Maryland Avenue, South	Grade, gravel, and sidewalks	4,991 92
C Street, South	9th Street to 13½ Street, West	Grade, gravel, and sidewalks	9,487 51
H Street, North	Vermont Avenue to Pennsylvania Avenue, West	Pave with asphaltum	*27,943 26
I Street, North	17th Street to Pennsylvania Avenue, West	Pave with asphaltum	17,748 00
13th Street, West	P Street to R Street, North	Grade and concrete carriageway	12,260 90
13th Street, West	R Street to Boundary, North	Grade and gravel carriageway	5,752 92
N Street, North	22d Street to 23d Street, West	Repair gap in filling	2,885 50
Vermont Avenue	P Street to R Street, West	Grade and concrete carriageway	16,871 53
Vermont Avenue	R Street to Boundary, West	Grade and macadam carriageway	21,606 85
C Street, South	New Jersey Avenue to 1st Street, West	Grade	19,950 00
F Street, North	2d Street to 6th Street, East	Grade	4,370 00
New Jersey Avenue	N Street to Boundary, West	Grade, gravel, and sidewalks	16,417 89
New Hampshire Avenue	Q Street to 16th Street, Northwest	Grade, gavel, and sidewalks to T Street	15,069 45
New York Avenue	North Capitol Street to Boundary	Grade	18,375 00
22d Street, West	M Street to Massachusetts Avenue, North	Grade, gravel, and sidewalks	14,871 11
3d Street, East	Virginia Avenue to M street, South	Grade, blue-rock pavement and sidewalks	7,700 73
7th Street, East	Penn. Avenue to South Carolina Avenue, South	Complete concrete carriageway	7,323 11
8th Street, East	South Carolina Avenue to K Street, South	Complete macadam	6,271 20
F Street, North	Maryland Avenue, East, to 2d Street, East	Grading, curbing gutters, footwalks, and gravel carriageway.	10,061 84
Virginia Avenue, South	South Capitol Street to 4th Street, East	Curb, gutters, footwalk, and gravel carriageway	11,456 48
		Repair of Tiber arch and construction of overflow	13,000 00
		Construction of auxiliary main sewers	400,000 00
	All parts of Washington and Georgetown	Extension of lateral sewers	30,000 00
			913,824 08

* 16 feet, width of railroad-track, deducted.

APPENDIX B.

Funded Debt and Sinking-Fund.

OFFICE OF THE COMMISSIONERS OF THE SINKING-FUND,
Washington, D. C., November 11, 1878.

SIR: I have the honor to transmit herewith a copy of an estimate for interest, and sinking-fund, for the funded debt of the District of Columbia, for the fiscal year ending June 30, 1880; also a copy of my letter enclosing the same to the Commissioners of the District of Columbia.

Very respectfully your obedient servant,
JAS. GILFILLAN, *Treasurer U. S.*

Hon. JOHN SHERMAN,
Secretary of the Treasury.

OFFICE OF THE COMMISSIONERS OF THE SINKING-FUND,
Washington, D. C., November 8, 1878.

GENTLEMEN: I have the honor to enclose herewith estimates of amounts required to pay interest on and create a sinking-fund for the payment of the funded debt of the District of Columbia, for the fiscal year ending June 30, 1880, amounting to $1,284,145 37.

The first two items of $15,000 each, in the estimate for sinking-fund purposes, are required by law to be set apart annually for the gradual redemption of the market and water-stock bonds; the remaining items are the annual amounts required under existing laws to redeem the bonds at maturity, and are estimated as if the sinking-fund had been originally created and invested in the bonds.

Very respectfully,
JAS. GILFILLAN, *Treasurer U. S.*

Hon. COMMISSIONERS OF THE DISTRICT OF COLUMBIA.

Estimates of appropriations required for the service of the fiscal year ending June 30, 1880, *by the Commissioner of the Sinking-Fund of the District of Columbia.*

General object, (title of appropriation,) and details and explanations.	Date of acts, or treaties, providing for the expenditure.	References to Stats. at Large, or to Revised Statutes.			Estimated am't required for each detailed object of expenditure.	Total amount to be appropriated under each head of appropriation.
		Vol. or R.S.	Page.	Sec.		
GENERAL EXPENSES, DISTRICT OF COLUMBIA.						
Interest on Funded Debt—						
$3,995,000 permanent-improvement 6 per cent. bonds	Assembly, Dist. of Columbia, July 10 and Dec. 16, 1871.				$239,700 00	
1,150,000 funding-loan 6 per cent bonds	Congress, May 8, 1872	17	86	2	69,000 00	
660,000 funding-loan 6 per cent. bonds	Assembly, Dist. of Columbia, June 20, 1872.				39,600 00	
670,000 permanent-improvement 7 per cent. bonds	Assembly, Dist. of Columbia, June 23 and 25, 1873.				46,900 00	
150,000 market-stock 7 per cent. bonds	Assembly, Dist. of Columbia, Aug. 23, '71; June 19, '72.				10,500 00	
423,000 water-stock 7 per cent. bonds	Assembly, Dist. of Columbia, July 20, '71; June 26, '73.				29,610 00	
53,000 general stock, 5 per cent	Corporation of Washington, August 19, 1828.				2,650 00	
685,000 general stock, 6 per cent	Corporation of Washington, October 25, 1843.				41,100 00	
47,500 canal stock, 6 per cent	Corporation of Washington, April 14, 1847.				2,850 00	
178,300 general stock, 6 per cent	Corporation of Georgetown, Appropriated.				10,698 00	
20,000 general stock, 8 per cent	Corporation of Georgetown, May 12, 1871.				1,600 00	
20,000 bounty stock, 6 per cent	Corporation of Georgetown, September 24, 1864.				1,200 00	
30,000 market stock, 6 per cent	Corporation of Georgetown, January 9, 1864.				1,800 00	
281,750 funding-loan, 5 per cent. bonds	Congress, June 20, 1878	20	208	1	14,087 50	
13,743,250 funding-loan 3.65 per cent. bonds	Congress, June 20, 1874; February 20, 1875.	18	120		501,628 62	$1,012,924 1
Sinking-Fund—						
Market-stock bonds, (for gradual redemption)	Assembly, Dist. of Columbia, Aug. 23, '71; June 19, '72.				15,000 00	
Water-stock bonds, (for gradual redemption)	Assembly, Dist. of Columbia, July 20, '71; June 26, '73.				15,000 00	
Permanent-improvement 6 per cent. bonds, (for redemption at maturity.)	Assembly, Dist. of Columbia, July 10, 1871.				101,509 00	
First issue of permanent-improvement 7 per cent. bonds, (for redemption at maturity.)	Assembly, Dist. of Columbia, June 23, 1873.				7,055 28	
Twenty-year 6 per cent. funding bonds, (for redemption at maturity.)	Congress, May 8, 1872	17	86	2	29,183 84	
Thirty-year 6 per cent. funding bonds, (for redemption at maturity.)	Assembly, Dist. of Columbia, June 20, 1872.				7,772 27	
Fifty-year 3.65 bonds, (for redemption at maturity)	Congress, June 20, 1874	18	120		95,700 86	
						271,221
Total						1,284,145 3

CONTRIBUTIONS

TO THE

SCIENCE OF HYDRAULIC ENGINEERING.

BY

EWD. FONTAINE,

PROFESSOR OF THEOLOGY AND NATURAL SCIENCE, MEMBER OF THE NEW YORK HISTORICAL SOCIETY, THE HISTORICAL SOCIETY OF MARYLAND, &c., AND OF THE ACADEMIES OF SCIENCE OF BALTIMORE, NEW ORLEANS, &c., AUTHOR OF "HOW THE WORLD WAS PEOPLED," &c.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1879.

PREFACE.

I thought first of presenting the following contributions to the science of Hydraulic Engineering in the usual form of a plain methodical work for the instruction of students. But certain objections suggested by the recollection of my painful experience in the study of such treatises inclined me to give it to them in a composition which they will find more entertaining, and I hope equally instructive.

It is usual for text-books, and especially those of the exact sciences for the use of schools, to be divested of all the adornments of fancy. They aim at conciseness of style, and smallness of bulk. Such books may be cheap and marketable, but they are exceedingly dry and uninteresting; and they are difficult to understand and easily forgotten. Arithmetics, Algebras, Geometries, and the text-books on Civil and Military Engineering, and Navigation, and even treatises on the most sublime of all the physical sciences, *Astronomy*, used in our Military and Naval Academies, and all our institutions of learning, almost without an exception are of this dry, stony, and icy character, utterly devoid of every tint and trait of beauty which can attract the attention, charm the imagination, and impress the memory. When I was a youth I studied Horner's Anatomy; and the ludicrous plainness of his descriptions of the wonderful details of the material tenement of the immortal soul amused me. But why should not a book descriptive of bones be "dry as a bone"? And what room for "the play of fancy" is there in a treatise on "the theory of curves"? The writers of such works are hardly capable of giving a correct answer, for they are usually totally devoid of the poetical faculty, as the imaginative youths who are forced to study them know to their sorrow. It is generally the severest toil and torture of their ardent young lives; and through all their future years the most brilliant geniuses among them look back upon the ordeal of their mathematical course with horror. The fault is in the writers of the text-books, and not in the noble sciences which they dissect, skeletonize, and present in modes the most ghastly and repulsive. The disciples of Euclid, Archimedes, and Newton might make their books a little more pleasing by a few anecdotes of these great men illustrating their discoveries, and by adding a few observations directing attention to the important uses to which their sublime problems may be applied. Elihu Burritt has written a really learned and agreeable text-book on Astronomy. Sir William Jones, in his treatise on "Bailments," has proven how interesting one of the very dryest of all the subjects of the common and statute law of England may be rendered by a writer of genius. Richerand made the study of human physiology attractive. Cuvier exhumed the fossil bones of the extinct mammalia, and robed the ancient rocks in which they were buried before "the flood" with the radiance of a resurrected world. Fortunately the classic historians and poets of ancient Greece and Rome are yet studied as text-books in our academies and colleges; and the boy who quickly forgets all that he learned with difficulty of "quadratic equations" and "conic sections" will remember forever the delightful narratives of Cæsar and Xenophon, the orations of Cicero and Demosthenes, and the lays of Virgil and Homer.

It should never be forgotten by those who write books which they intend to be read and remembered, that all minds grasp and comprehend most easily, and all memories retain most

tenaciously, whatever is most exciting and pleasing to the imagination. This must be my excuse for whatever of "the poetry of science" may appear in these brief lectures. The unpoetical mathematician would prefer the subjects embraced by them presented in the forms of skeletonized diagrams and problems bristling with algebraic signs, and geometric angles, tangents, and curves. He cannot discern the beauty, or discover the use of "the froth and foam" and the bubbles which glitter with prismatic hues upon the Mississippi's mammoth tide, and he looks with contempt upon the lilies and loti which sparkle upon the bosoms of the placid lakes, and fails to see the gorgeous and lovely profusion of foliage and flowers which wreathe and veil their banks and shores. He prefers by the four rules of the science of numbers to estimate the cubic inches of water which they contain, or the precise amount of the mud which causes their turbidity or forms their deposits. I admire the patient toil and useful taste for calculation of our practical operative mathematicians; and I am exceedingly anxious to see them engaged in the useful task of applying the hydraulic plans suggested in these lectures. They delight in making all the estimates of the cost of the materials and of the labor which their application will require in all its details, and which I have carefully omitted. My object has been to give plain and palpable outlines of plans very necessary for our welfare, the details of which any practical mathematician can supply, and which any efficient mechanic can execute without understanding the technical terms of science.

I have another benevolent object in view in presenting these important and easily applied principles of hydraulics in the simple form of lectures, precisely as I delivered them in New Orleans. If the General and State governments of our country should long procrastinate, or neglect entirely the application of proper plans for the drainage and irrigation of our public alluvial lands, and the prevention of their overflows, in many instances corporations or individuals who own such lands may improve them without the aid of either the Federal or State government, if they have the ability to utilize the directions I have given them. Although they may not be able to remove the obstructions to the navigation of the rivers which are the property of the United States, and which it is the exclusive duty of the General Government to improve, individuals have the right to prevent the inundation of their own lands, and to drain and irrigate them if they have the power and choose to exercise it.

The science of Hydraulic Engineering as applied to the control of water-currents has not kept pace with the march of this age of progress, and but few additions have been made to the text-books embracing this department of Civil Engineering which were taught in our institutions of earning thirty years ago. I am not aware that any of them written before or since 1832 teach the principles explained in these lectures which I here present as a few contributions to assist the present and future labors of hydraulic engineers. I hope that whatever is new and useful in them will find a place in the improved works which at no distant day will be prepared for students, and that they will apply it in improving the condition of our country and other lands.

If any one who reads these essays doubts whether the principles enunciated and the rules given to direct their application are nothing more than mere untried theories, I assure the skeptic that I have tested each one recommended by the most elaborate and careful experiments. Some of the most valuable discoveries were made while I was making experiments to apply practically and cheaply the principles and working plans of nature in utilizing water in motion.

IMPROVED METHODS

OF

HYDRAULIC ENGINEERING,

FOR

CONTROLLING AND UTILIZING WATER CURRENTS,

AND

ITS GENERAL APPLICATION;

Also, its specific appliance—

1st, TO DRAINAGE AND IRRIGATION;

2d, TO THE IMPROVEMENT OF LAKES AND HARBORS: AND,

3d, TO A GENERAL LEVEE SYSTEM CONNECTED WITH JETTIES, TO GIVE PERMANENCE TO BANKS AND SHORES, TO REMOVE BARS, SHOALS, AND OTHER OBSTRUCTIONS TO NAVIGATION, AND TO GIVE FIXEDNESS TO THE BEDS OF RIVERS, AND SO TO DEEPEN THEM AS TO PREVENT OVERFLOWS.

BY

EWD. FONTAINE.

INTRODUCTORY ESSAY

ADDRESSED TO THE PEOPLE OF THE CITY OF NEW ORLEANS, LA.

[The introduction and the whole of the subjects embraced in this pamphlet were delivered by invitation to the New Orleans Academy of Sciences in three lectures, November 27 and December 4 and 11, 1877.]

A PLAN FOR DRAINING THE CITY OF NEW ORLEANS, AND FOR PREVENTING ITS INUNDATION BY THE LAKES AND THE MISSISSIPPI RIVER.

The greatest obstruction to the prosperity of New Orleans is the danger to the lives and property of its citizens, caused by the inundations and epidemics which have afflicted it, and with which it is continually threatened. The great river, varying in width from a half mile to a mile in the city, flows through it in an ever-changing channel caused by its Titanic current. The average depth of this vast volume of fresh water from Baton Rouge to "the Passes" is about 100 feet, and its mean velocity is 4 miles per hour. Within the city its surface at the lowest stage of its water-level is only 5 feet above that of the Atlantic Ocean, the Gulf of Mexico, and the adjacent lakes connected with it, and which rise and fall with the oscillations of its tides and storms. During the period of its greatest floods the surface of the river is elevated about 15 feet above that of the Gulf. The extreme variation of its surface level is about 10 feet. Its velocity corresponds exactly with the volume of its water or the oscillations of its surface. During the acme of its flood it flows with the fearful speed of 5 miles per hour. When at its lowest stage, and in its most attenuated condition, its course is slackened to 3 miles per hour. Its average velocity is about 4 miles per hour.

A peculiarity of the current of the Mississippi which is too often disregarded by those who live upon its banks, and by the engineers who attempt to secure them against undermines and overflows, is the alarming fact that *it flows as swiftly at its bottom, or upon the deepest depressions of its bed, as it does upon the sides of its crumbling banks, or at its surface!* Numerous experiments made by the most competent engineers of the United States Army have demonstrated this singular fact. Immense *water-logged* trunks of trees and large masses of tenacious clay have been found by them rolling and sliding upon the bottom of the river in the channel where it is deepest, and 100 *feet below the surface of the Gulf*, propelled towards it by this gigantic current with a velocity equal to that which moves the light driftwood floating upon its waves. Sometimes the bottom current is hurled by some obstruction to the top, where it swells above the surface level and rolls away in angry eddies. It is this bottom current, acting under the pressure of the immense depth and weight of the fluid-moving-mass above it against the deep sand strata underlying the layers of clay and other materials which compose its banks, and the whole alluvial Delta, which causes all the disasters of crevasses, inundations, and the engulfing of plantations and human abodes, and which continually menaces this city with destruction. One of the most distinguished engineers and soldiers whom Louisiana has produced, General G. T. Beauregard, can testify that he found with the sounding-line two spots directly in the current at the time he was making his observations on the cross-sections of the river near the Third District Ferry, each 240 feet deep.

The cross-sections marked on Harrison's map of the city in 1846, in the Academy of Sciences, and which was used by the engineers before the civil war as the best topographical authority, demonstrate the same appalling truth in regard to the tremendous undermining and excavating force of the bottom current of the Mississippi. At the time it was making the enormous area of batture

between Tchoupitoulas street and New Levee street, it was excavating trenches on the right bank 162 feet deep, and filling up others which it had dug out under the left bank, now covered with great blocks of buildings, 182 feet deep. *The same mammoth force is now undermining a mile of the Crescent City front with the bottom current deflected against it by the diagonal projection of the peninsula of Algiers.*

I give these disagreeable facts in regard to the physical geography of the foundation of New Orleans, and the peculiarities of the current of the mammoth river, *which will certainly rearrange all of the materials which compose it, unless it shall be controlled*, in order that the absurdity may be made obvious of building superficial levees, wharves, or houses upon the margin of the surface of the water, while this deep and terrific bottom current is left unchecked to undermine and engulf all the vain works of man erected upon stratified alluvium in which no rock is found even at a depth of 630 feet! And also that the minds of those most interested may be prepared to investigate the merits of the plan proposed in this essay for guarding them against this threatened danger.

I will mention, in order to show that this danger is not imaginary, that I made a map for the Academy of Sciences while I was its secretary, and lecturer in the chair of geology, plotted from the boring of the Artesian well in Canal street, between Carondolet and Baronne, made in 1856, and superintended and accurately reported by a committee of the most competent chemists and geologists of that institution, which is, I suppose, yet among its archives, an examination of which will show that *the foundation of New Orleans rests upon no rock for at least* 630 *feet;* but that the surface of the river flows and the corner-stones of all the edifices of the city are laid above 57 strata of the most fragile and friable materials, irregularly distributed by the alternating and conflicting currents of the *ancient Mississippi* and the Gulf of Mexico, and all the upper layers to a depth of 200 feet have been rearranged by *the modern river.*

In a lecture on the Physical Geography of the Mississippi, appended to my published work "How the World was Peopled," and the notes and diagrams added, p. 330, I have shown how the present river is acting its part as "a pigmy in giant's clothes" in rearranging the deposits made by its mammoth predecessor which drained the great mediterranean sea which existed after the glacial epoch of which the large fresh-water lakes of the United States and British America are the remains, and which made the Delta of Louisiana. I have discussed this subject at greater length in a lecture delivered in Washington City to the two Houses of Congress, April 30, 1874, published in a pamphlet, on "The Peculiarities of the Physical Geography of the Mississippi River and its Delta," and the methods for removing the obstructions to the navigation of its mouths.

One of these recent layers was so nearly *fluid* that the Artesian auger sunk into it 11 feet by its own weight! This rested upon more solid materials, beneath which, and 330 feet below the city, was an enormous stratum of sand, full of water like that of Bladon Springs, and which rose above the surface in an Artesian stream at the rate of six gallons per minute. This great sand-layer was 140 feet thick! Underneath it were other strata of sand, clay, and mingled alluvial materials, one of them pure clay 60 feet thick. Yet all this stratified alluvium was not only *post-tertiary* but *post-glacial* in geological age, and so recent that none of the wood, shells, or other vegetable and animal matter which it contained was petrified or fossilized in any degree. At present there is no human device in operation to prevent the bottom current of the river from penetrating and removing the whole of it, and sweeping it into the Gulf with everything erected upon it.

In several lectures on the cause of the velocity of the current of the Mississippi River, and the direction of the great currents of the ocean, delivered in the New Orleans Academy of Sciences, I have, for the sake of scientific accuracy in the nomenclature of physical geography, termed those which fall from the equator towards the poles, like the Kuro Siwoo or Black Current of the Pacific, the Madagascar of the Indian, and the Patagonian and Gulf Streams of the Atlantic Oceans, *centripetal;* and those which rise from the poles to the equator, like the Labrador and Corean from Davis's and Behring's Straits, *centrifugal.*

While the great river thus menaces the foundations of the city with "sap and mine," the combined forces of the cyclones of the centripetal ocean current called *the Gulf Stream*, and the salt waves of Lakes Pontchartrain, Maurepas, and Borgne, threaten to "carry it by assault," and sweep it from the earth with wind and water "mingling in their might."

I do not like to be "a prophet of evil," and to lacerate the sensibilities of our afflicted people with woeful *Cassandriads* or *Jeremiads;* and I would not call their attention to another enemy whose fatal attacks are more dreaded by us than engulfment by the river, or destruction by the wings of the typhoon and the waves of the lakes, if I did not at the same time present them with a remedy to secure them.

While "the Great Father of Waters" rolls through our city his fearful but yet beneficent sea of living and purifying water, dispensing health and wealth to all who will utilize his power and receive his gifts, and while he offers his services to irrigate and cleanse our city, and to pour into it the commerce and riches of all lands, threatening at the same time to scourge it if his proffered favors are spurned, on either hand lie dead lakes, bayous, lagoons, and bogs filled with stagnant and fœtid fluid, and festering with pollution. Their arms, in the form of canals, ditches, and open gutters, green with scum, and mephitic with every form of microscopic animalcule, or vegetable algæ or fungus, whose *winged eggs* or invisible *seed-spores* ride upon the wings of the wind to spread malaria and death, penetrate every part of the city. These open elongated cesspools are the swords entering its vitals. All the filth of it enters them; and after an exposure to the face of the sun to shock all human eyes, and to offend all nostrils, its rank and mephitic odor is diffused through the air, which it makes deadly with cholera, yellow fever, and all the forms of malarial disease which compounded filth can generate in Serbonian bog or Stygian lake.

Wise men are guided by their own eyes, and follow their own noses. Our Creator has given us *noses* to guide us. Whatever offends the nose warns us to remove it or get away from it. These open gutters, sluggish canals, and stagnant ditches and slimy ponds are disgusting to the sight and sickening to the smell. Their evaporation is deadly Avernian fog. They ought to be dried up, or piped and covered under ground, to be seen and smelt no more. They are the principal sources of our epidemics.

I repeat emphatically the assertion with which I commenced this essay, that the danger to the property and lives of our citizens caused by the sudden submergences of its banks by the perpetually shifting and undermining *bottom current* of the Mississippi, the continually recurring inundations of the city by the swells of the lakes, produced by the cyclones of the Gulf of Mexico, and the epidemic fevers generated by the stagnant water and undrained pollution of its site, are the main obstacles to its growth and prosperity. Bad government has lent its aid to these destructive agencies. But no matter what beneficent civil revolutions may occur in our city and State, the ruling powers of neither can escape the reproach of negligence, parsimony, stupidity, a disregard of the public weal, and whatever else, apart from theft, robbery, and murder, constitutes *bad government*, who permit these obstacles to the prosperity of New Orleans to continue. They drive thousands from it who come to live in it. Unable to endure these nuisances and perils, they leave it with their families, and carry their capital and business to safer and more pleasant cities. They prevent the settlement of hundreds of thousands of refined and intelligent people and the investment of many millions of dollars in New Orleans. They give all the most enlightened and virtuous citizens who are compelled by circumstances to live in it an aversion to their abode. They cripple or destroy schools and churches, as well as manufactories and business establishments of all kinds. No intelligent and affectionate parents are willing to live and labor, educate their children, and plant their posterity where their eyes are perpetually haunted with hideous rills and pools of filth, and their nostrils filled by day and night with abominable smells; and where they and their offspring are liable at any time to die of some form of fever generated by foul putrescence, to be swallowed by the subterranean current of the Mississippi, or drowned by a flood from Lake Pontchartrain. Thus the fire of patriotism is quenched, and all the useful and magnificent works which only patriots perform for the utility and glory of the homes of their nativity or adoption are prevented. But few people, whether native or immigrant citizens, love New Orleans, or regard it as their permanent abode, or the future home of their posterity. The most of her residents consider it as a temporary *locum tenendum*, and a place only to be occupied while the necessity endures which compels them to brave its nuisances and dangers. They are determined to go with their families, as soon as they can, to live and die in some cleaner and less endangered city.

The plan which I propose for abating these nuisances and removing these threatening and attacking perils would effect a radical metamorphosis in the physical condition of the city, and a change as thoroughly beneficent in the sentiments, morals, character, and circumstances of its inhabitants. It would transform all the virtuous and intelligent among them into patriots blessed with health and prosperity, willing to live and labor for a home which they would love as their only cherished earthly abode, and which would be the most favored, lovely, and magnificent city beneath the sky.

Lake Pontchartrain must not be used for the drainage of the city. All bayous and canals intersecting it must be separated from this lake. While the connection between them exists all drainage plans for health and safety from overflows will be worthless and perilous.

PART I.

DRAINAGE AND IRRIGATION

BY

EKMUZESIS;

ITS GENERAL APPLICATION TO ALL MARSHY AND OVERFLOWED LANDS INTERSECTED BY RUNNING WATER, OR NEAR TO NATURAL OR ARTIFICIAL WATER-CURRENTS, WHOSE BOTTOMS ARE LOWER THAN THE BEDS OF THE SWAMPS AND SHALLOW LAKES TO BE DRAINED, AND ITS SPECIFIC APPLIANCE TO THE DRAINAGE AND WATER-SUPPLY OF THE CITY OF NEW ORLEANS AND THE SWAMP-LANDS OF LOUISIANA.

PART I.

DRAINAGE AND IRRIGATION.

I present this connected plan, consisting of three parts, as a whole system which is constructed to suit the future extension of New Orleans. Portions of each of these three parts ought to be applied immediately. The rest may be utilized as the expansion of the area of the city may demand it.

First. The drainage of the city and the malarious marshes near it, and their irrigation after their desiccation.

Second. Its protection against inundations from the lakes, and the improvement of Lake Pontchartrain for the objects of health, commerce, and pleasure.

Third. The prevention of the destruction of property by the shifting of the channel of the Mississippi River, the undermining action of its current causing the submergence of its banks with all the superficial levees and structures erected upon them, and the gaps and crevasses through which its waters at flood-tide rush in destructive torrents over the plantations of its valley.

The whole cost of the drainage of New Orleans on both sides of the river by the Bonnet Carré and Gretna aqueducts and their sewers will be less than $2,500,000, if the whole work is done honestly and faithfully.

While I ask you to fix your minds upon the whole of this hydraulic plan, which ought to be executed as *a whole*, unmutilated by any work upon either of its parts which might mar its unity, I will now present a brief elaboration of its three separate portions. I can only give, without being tedious, its distinct and intelligible outlines, leaving the details of the work to be prepared by the engineers who will have the labor and honor of its mechanical execution. After mastering these outlines and the few new principles involved, and whose application is necessary for its successful completion, each part of it will be found so simple that but little genius or talent will be necessary to enable any honest and energetic engineer to execute the whole plan.

I hope your minds will not be confused by a view of the magnitude and cost of this plan in its unity as it will appear to the imagination. Only a part of it will be constructed at the expense of the city, which is the first part on drainage within the city by two canals with aqueducts. The pipes for drainage into these aqueducts necessary now ought to be laid as soon as possible; but the most of them presented on the maps of the complete plan may be added successively, year after year, as the future growth of New Orleans may demand their use. The drainage and desiccation of the marsh and swamp lands ought to be performed at the expense of the whole State of Louisiana, because she owns these overflowed and worthless bogs, and she alone ought to pay for their improvement. All the improvements suggested and explained in the second and third parts, and which refer to Lake Pontchartrain and the Mississippi River, should be done by the Government of the United States, in which alone is vested the title of these public waterways of commerce.

THE DRAINAGE OF THE CITY OF NEW ORLEANS AND ITS ENVIRONS, AND THE IRRIGATION OF THE RECLAIMED AND DESICCATED MARSHES.

To make this complete, in view of its future extension, and to secure its health, and especially its exemption from diseases caused by local malaria, in its present condition, the drainage should include all its environs, embracing the peninsula of Algiers, and all the area lying between the Mississippi River and Lakes Maurepas, Pontchartrain, and Borgne, with their connecting waters, about 400 square miles in extent, as speedily as it can be applied. I recommend the construction of

a *canal-aqueduct without locks*, 30 feet wide, 27 feet deep, and 36 miles long, taken out of the Mississippi River at Bonnet Carré Bend, and turned into it again a short distance above the Noyes Canal near the upper curve of the English Turn; and another of the same size, and 6½ miles long, across the neck of the peninsula of Algiers, from Gretna to a point below the English Turn, each outlet to enter the river at an angle less than 45° to the general direction. I suggest the depth of 27 feet in order that the bottom of the aqueduct may be below the beds of all the bayous, lagoons, and other stagnant waters and marsh-lands intended to be drained, and also that the mouths of the largest sewers may be covered entirely by the running water of the aqueduct. The water-level in the aqueduct must at all times be higher than the tops of the sewers in order that the suction by the attraction of cohesion of the fluid in the sewers by the larger volume of running water in the aqueducts flowing at an angle of from 11¼° to 45° in contact with their openings may be complete. The same rule must be observed where the sewerage is run into natural streams. Unless the proper angulation is observed the drainage will not be efficient. If the depth of 27 feet is not sufficient to cover the mouths of the large cylindrical sewers, the aqueducts must be made deeper, or the mouths of the sewers must be widened and flattened. The depth of the aqueducts must be measured, not from the natural surface, but from a line from the heads to the mouths drawn above the highest water-level of the river. For our present use, and for that of our successors for twenty years *probably*, these dimensions will be sufficient. In consideration of our financial depression, they may be constructed of wood, and they should not be used for any other purpose than that of drainage. They will last, and serve for that use only, and possibly be sufficient to accomplish the sanatory and other beneficial objects, for the fifth part of a century. But if before that brief period shall elapse, the growth and necessity of the city shall require it, the whole *aqueducts* will be enlarged; and others may be used for manufactories, irrigation, the supply of fire and other engines, and many other useful purposes. Various parallel aqueducts, separated from those made to convey the sewerage of the city, may be drawn from the same inexhaustible source, and conducted to the same safe and ample outlet, and confined in walls of iron, glazed pottery, or other costly and permanent materials such as the necessities of 5,000,000 of people may demand, and which their wealth and taste will enable them to construct.

With such a contingency as the necessity of future extension presented to us, in surveying the ground for our present humble work, provision should be made for the expansion which our more prosperous and powerful successors may give it. Therefore the breadth of an acre of land, or 210 feet, on each side of the canals, for the whole length of their course, should be reserved uncumbered by buildings, and unfettered by any private or other legal rights which might prevent the enlargement of the work to meet the demands of our multiplied posterity.

The modest wooden structures proposed will be amply sufficient for our present wants, and will tax sufficiently our depleted resources. Between the two points on the river selected for the inlet and outlet of the canal for the left bank in which the wooden aqueduct is to be built, the distance by the *mid-banks* channel of the serpentine course of the Mississippi is 46 miles. By the proposed canal the distance is only 36 miles. By this saving of *ten miles* the principle of the "cut-off" between bends, or greater *fall* and velocity of current, is secured. (See Plate IV, Diagrams 4, 5, and 6.) The planking with which the aqueduct is to be lined will run parallel with its course to avoid friction or any resistance to the rapid flow of the water. The bottom of the aqueduct must be dug entirely below the bottom of the Saint John Bayou, or that of the deepest tributary of the lakes which it will drain, and about eight feet below the lowest-water line of the Mississippi River, during the most attenuated stage. It must be dug its whole distance below the lowest water-level of the river, and also somewhat below the surface of the lakes, in order that there may be always in it a depth of from 8 to 15 feet of swiftly-running water. At proper intervals, about a quarter of a mile apart, spaces must be prepared and properly marked for the insertion in the sides and on a level with the bottom of the aqueduct of the main sewers. The size and number of these will depend upon the area necessary to be drained, and they can be constructed, and inserted successively as the necessity for their use shall arise. At least six of them are necessary now to drain the filth of the city and the contiguous marshes, and as many more should be constructed, to desiccate the swamps nearest to it, as its finances will permit. In order that they may perform their work well, all the pipes and sewers

must be made to enter the canals and each other at angles of from 11¼° to 45° *with the direction* of the course and current of the water. A greater angle than 45° will prevent their most efficient action. The main sewers should rest upon the bottom of the aqueduct, and their inner rims must be shaped to fit the inner surface of it; but no parts of the pipes or *sewer-ends* should fail to reach the inside surface touched by the water of the bottom current, and they should not project into it. If properly constructed the *ekmuzesis* will be complete. The bottom current of the larger body of water in the aqueduct passing rapidly by the mouths of the sewers, *by the attraction of cohesion will suck out* all the fluid they convey in contact with it. I recommend that the mouths of all these sewers be made of pottery, glazed on the inside, and crooked and shaped at the proper angle for insertion at the time they are moulded. All of their larger sections should be made of the same material.

The openings in these sections should all be *angulated on the same principle*, as we are taught by the *venous* circulation of our blood, which is the reverse of that of the *arterial*. The contraction of the heart propels the blood through the great arteries into the smaller, and diffuses it by propulsion throughout the body and into the little veins; but it is returned by them to the heart by *suction*. The little veins run into the greater at various angles, and discharge their blood into the *venæ cavæ*, or larger *sanguiducts*, which finally pour it into the right auricle of the heart. I hope this principle and this rule of *angulation* will be observed in the construction of the entire sewerage and drainage of this city, and in the course of time of the whole Delta and of all other swampy areas. The bottoms of the canals should be cut low to give all the sewers and the smaller pipes a sufficient fall, which ought to be carefully observed by the engineers who place them in position. Perpendicular tubes may be dropped into them from all necessary points and covered by grating or sieves of iron to strain the trash and drain the surface rain-water into the canals. But in the construction of all the underground sewerage the principle of the *vena cava* should be observed. This is *ekmuzesis*, and if it shall be wisely followed every particle of the noxious and offensive filth of this city will be easily and harmlessly discharged by the aqueducts into our grand *vena cava*, "the Father of Waters," which will pour it into the abyss of the great heart of our commerce—the Mexican Gulf.

Our language is already so overburdened with useless words, many of them synonyms, while the most of them are insignificant, and the whole worthless addition to our mother tongue mainly the work of shallow-minded pedants who make it year after year more difficult to be read, spoken, or understood, that an apology is due to the whole world by the man who ventures to give a new word to our cumbrous dictionary. *Ekmuzesis* is the only word I ever coined. I invented it, not because it is a thundering Greek derivative, from *ek*, out of, and *muzeo*, to suck, which in a scientific controversy, and especially in a metaphysical contest such as theological disputants sometimes wage furiously, is said to be worth a thousand arguments, but for the reason that I could find no word in our language which properly designates the application of the principle of nature by which fluids flowing in large channels, by the attraction of cohesion suck out and blend with their currents those which are brought into contact with them through smaller ducts. The phrase "*sucking out*" is rather rough and awkward, and I therefore prefer my sole coinage, and only offense to my native language, *ekmuzesis*, which expresses the idea as well; but for the use of which I beg pardon of all who read, write, or speak it.

I am afraid, while I describe the beautiful invention of *ekmuzesis*, that you may overlook the important fact that the efficiency of the plan of drainage I recommend does not depend upon the successful application of this useful scientific discovery. The whole plan of drainage was elaborated before I made it. The leading idea of the whole plan is *to drain the noxious fluids of the city and the contiguous marsh-lands into deep canals enclosing well-constructed aqueducts to prevent these cut-offs, which will be shorter and swifter than the river curving around the bends, from enlarging and making new river-beds. These deep aqueducts are to be taken out of the deep current of the river and turned again into its depths by a shorter route than the natural serpentine course of its waters; and all the mouths of the sewers intended for low marsh-drainage must descend to the level of the bottom currents of these canals, which they must be made to reach by properly graduated falls.*

In every instance the mouth of the sewer must be entirely covered by the water in the aqueduct, bayou, or river into which it enters, in order that the cohesion of the fluids and the suction of the

smaller by the larger body in motion may be complete. The larger body will always draw the smaller along with it if the discharging-pipes or sewers are angulated properly from $11\frac{1}{4}^\circ$ to less than 45°. At less or greater angles they will work badly or not at all.

There, at their points of contact with the aqueducts, their contents must be discharged into them either by *ekmuzesis* or by some other mechanical contrivance.

It was while seeking for the simplest, the most efficient, and above all other considerations *the cheapest device*, that I made the discovery of *ekmuzesis*. I had studied the plans of various draining-machines and steam-pumps for transferring the contents of our vile cesspools, Augean stables, and *chartered Stygian and death-dealing canals* into a purifying aqueduct of living and life-saving water; and after revolving in my mind the *known* and many *untried windmills* and *steam-drainers*, I found them all either too expensive, or unreliable contrivances which would not work during the raging of a cyclone, when a deluge is falling from the sky, and when Pontchartrain, lashed into fury by the wings of the tempest, threatens to overwhelm the city with its waves. When we want these *tricky servants*, especially our draining-canals and draining-machines, to work the hardest and fastest to save us, the steamers stop work or desert their posts in despair, and the canals "join the enemy," and swell the forces of the invading flood. They, and all the devices hitherto used, seemed to my mind as impotent to protect us against the combined powers of the typhoons and lakes as the much-used *and much-abused broom* of the sage Dame Partington to sweep the swelling Atlantic from her cottage floor. I then invented a simple water-wheel to be revolved by the current of the canal, and which would work a powerful pump by night and day, and in a tempest as well as in the calmest weather—a cheap wooden contrivance, which would only require one hand to grease it and keep it in order, and which would perform its labor even without grease or any attendance, and work the hardest and fastest when the water is the highest. Six of these inexpensive machines, which consume nothing, and which are almost self-acting and self-supporting, stationed at the mouths of the main sewers, a quarter of a mile apart, to discharge their contents, are cheap enough for any reasonably economical plan of drainage; and I cordially recommend them to all those who cannot grasp a new idea and who cannot comprehend the utility of a new device until some bolder spirit uses it successfully.

Here with these water-wheels, simple as the *flutter-mills* made by little mountain boys, and placed upon the rills of their native glens, I might have closed my drainage plan. But in view of the diminished resources of our city and State I concluded to devise something even cheaper than my little "flutter-wheels"; and as you know that "necessity is the mother of invention," I can say with truth that the poverty of New Orleans, and the stern necessity for rigid economy which oppresses our whole State, is the mother of *ekmuzesis*.

IRRIGATION.

(See Plate IV, Diagram 4.)

It is easy to see how the same aqueducts constructed for drainage may be used for irrigating the bogs and marsh-lands they desiccate. The Mississippi, and the bayous leading from it, like the Atchafalaya, Lafourche, and others; and its great affluents, like the Red and Arkansas, and all the smaller tributaries, during their periods of flood have their water-levels high above the surfaces of the cultivated fields which they intersect. If these fields lie near their banks, and if their channels are prevented from shifting by jetties properly angulated to give permanency to their beds, the sewers and subsoil ditches may be conducted at proper angles directly into their deep bottom currents. I only recommend the use of aqueducts where the swamps to be drained are remote from the running rivers and bayous or where these streams are unrestrained and shift their banks, and in their unbridled condition would fill the sewer-mouths with mud or wash them away. But *superficial irrigating-ditches should be run directly above the subsoil drainers into the plats of ground* needing irrigation during the droughts of May and June, when the flood is at its height. When the water they convey from the *top currents* to the fields and gardens has irrigated them sufficiently, *through openings into the sewers* it can all be returned by *ekmuzesis* into the aqueducts; and all the expense of draining-machines may be obviated.

This plan is so simple, and will effect the drainage of all the marsh-lands of our State so cheaply, and render them so exceedingly valuable, that it is the duty of our representatives to stop their sale immediately at the low price now fixed as their value, and use the whole valuable and easily reclaimable area to pay our State debt, and at no distan t day to so lease them as to provide for the expense of the State government and the support of our schools, and at the same time to exempt the people of Louisiana from all State taxation.

That this is entirely practicable is made evident by the following facts: There are 9,500 square miles of overflowed lands, nearly all of which belong to the State of Louisiana. Of this area 5,200 square miles are sea-marshes and trembling prairies overflowed by salt water during storms on the Gulf. Much of this area can be reclaimed by *ekmuzesis* where the deep river and its outlets run near it into the Gulf. The rest can only be reclaimed by the means used by the Dutch, or appliances similar to those by which that energetic nation has conquered so large a portion of Holland from the sea. But the State owns about 4,300 square miles of fresh-water, wooded swamps, easily drained. Four hundred square miles of this State land lie near this city and its immediate commercial waterways. Each acre, of the 256,000 acres, if reclaimed, would produce from one to three hogsheads of sugar. Even if the whole were sold for only $100 per acre it would yield $25,600,000, and double the amount of the State debt, which is about $12,500,000. The rest of the 3,900 square miles could certainly be leased on such terms as to exempt our people from all taxation.

Areas of these overflowed lands can be successively drained by the State and brought into the market as the necessity for raising funds to endow a system of State education, or to replenish the State treasury for any purpose whatever, may arise. An act of the legislature should be promptly passed *prohibiting their sale at present.* If it is not, as soon as capitalists discover how easily and cheaply they can be drained, individuals and land-rings will be apt to secure them; and they will be bought for purposes of speculation, and our posterity will be deprived of their incalculable benefits. Such reckless, *golden-egg-goose-ripping legislation* has characterized our State and Federal Governments since their origin. A greater wrong to our descendants could scarcely be conceived by selfish and cunning covetousness, or be perpetrated by cold-hearted stupidity and corruption combined. The only argument for its continued criminality is that these lands are worthless as they are, and that it is better to sell them to private individuals and let them be cultivated in rice, sugar, cotton, and fruit, or to be used as improved pastures for flocks and herds, than to lie idle as reed-marshes and cypress-swamps. This is not so. Much of our marsh-lands is owned by wealthy corporations and private individuals. Their successful experiments in draining them by this method, or those made by the State, will make all such lands, whether public or private, rise in value. Let speculators buy and sell their own. The State should be *in no haste* to rob the future, and to squander the inheritance of her children. But it is said that our legislators *cannot be prevented* from passing such disastrous laws. If this is true then we have reached the *nadir* of corruption, and cannot find wise and virtuous representatives to mak e our laws. We do not deserve to be land-owners, or *freemen;* and are too stupid and corrupt to govern ourselves, which I am unwilling yet to believe.

When I reflect how the problem of *subsistence for the multiplying millions of our race* has perplexed wise and benevolent political economists, who have not been able to devise any provision for employing and feeding the vast multitudes of India, China, and other densely-peopled countries as they will inevitably increase in the near future without the intervention of the destructive agencies of pestilence and war, and how it *is solved by this discovery,* I am overwhelmed with wonder and gratitude in view of the grandeur of the beneficent results which will flow from its certain application. The impoverished myriads of the inhabitants of the marshy valleys of the Yanktsekiang, Hoang-ho, Cambodia, Ganges, and Indus will not perish nor migrate for the want of lands to cultivate. Every untillable and uninhabitable bog and jungle can be reclaimed and transformed into the most prolific soil, to furnish abundant food for ten times the number of people who now live upon their alluvium. Every quagmire of the Danube, the Po, the Amazon, the Orinoco, and their tributaries, and all the great rivers of Africa, in the course of time will be dried and sanified by it. There is not a marshy region of the earth through which a canal of running water can be carried which will not be reclaimed

by it when the wants of a dense population shall demand it. The same aqueducts for draining and drying the marsh-lands will also be used in periods of drought for their irrigation. Ordinary ditches, leading from them when they are full of water, or simple water-wheels when their currents are below the levels of the fields, orchards, and gardens, will supply them with moisture when rain is wanted; and all the wasted water will be returned into the aqueducts by *ekmuzesis*.

This system of drainage and irrigation by the same simple contrivances will give a healthy and ample circulation of water to every river-valley independent of any supply from the clouds, and even enrich the sands of Sahara, and the great deserts of Asia and America, and all the sterile regions intersected by such rivers as the Nile, the Rio Grande, and the Colorado of the Great Basin. It will work as efficiently to nourish and cleanse the soil of our mother earth as the circulation of the blood by the arteries and veins supplies the human body with fluid, and purifies it from its stagnated and unhealthy excess. I know that we cannot fix any limit to the inventive power of the human mind, and I dare not assert that a better plan of drainage and irrigation may not be invented by some genius to whom the future may give birth, but I will say that no mode so simple, cheap, practical, and effective has yet been planned in the present era or in past ages; and I cannot conceive how it can be improved in any future period of time, unless a better plan for the circulation of the blood can be discovered than that which Eternal Wisdom has created, and of which this hydraulic system is an humble human imitation. It is but a copy of "nature's model," and the application of nature's hydraulic system—the wisest and best, because it is the work of God alone, whom it is our duty to worship and imitate.

This plan will drain every lake, swamp, or marsh intersected by an aqueduct, or by a river or running bayou whose bottom current is lower than the bed of such shallow waters and marsh-lands as need desiccation. By the same cheap and simple method all such spots may be irrigated after drainage without the aid of machinery, by surface ditches, when the water in the aqueducts or natural streams are filled by the spring rains, and flow with surface-levels above those of the lands near them. All the alluvial lands of the Mississippi, and other rivers with which I am acquainted, answer these conditions, and need these improvements. There are no cities whose plans of drainage may not be greatly improved by the proper application of these principles, and especially the *ekmuzesis* dependent upon the proper angulation of sewers and draining-pipes.

When it is necessary to drain swamps into bays like the Delaware and Chesapeake, which have tides, and which have to be utilized in consequence of the impossibility of making the culverts or sewers reach the direct onward flowing ocean currents, as represented by Diagram 3, Plate VII, the drainage must be effected by forking the outlets of them as in Diagram 4, Plate VII.

The Tiber Creek and other sewers might be made on this principle to drain the flats of Washington City into the Potomac. While the general direction of the sewer near its mouth should be at right angles to the course of the river, it should be forked into divisions each of the same size, and equal in capacity to the main sewer. They should enter the bottom currents of the river at angles of about $22\frac{1}{2}°$, and be at all times covered by the water of the river, so as to expose the two diverged mouths alternately to the suction of the ebbing and flowing tide. When the tide is flowing up the river the mouth (*a*) will be idle, but the mouth (*b*) will receive the *ekmuzesis* of the ascending tide and pour the contents of the sewer into it. When it ebbs this upper mouth (*b*) will be calm, and the lower mouth (*a*) will be sucked by the outflow, and discharge vigorously its filthy waters into the ocean-bound river. (See Diagram 4, Plate V.)

This plan may be applied successfully to the drainage of the Kidwell flats, and all marsh-lands situated upon tide-water creeks, inlets, gulfs, and bays. But their tidal currents must be first utilized so as to give fixedness to the channel-beds and permanency to the shores by the application of the method for utilizing ebbing and flowing or tidal currents, illustrated by Diagram 9, Plate III.

The mouths of the sewers must always be covered by the water into which they discharge their contents, in order that they may receive the full force of the suction of the attraction of cohesion, and also to prevent their mephitic matter from tainting the air.

PART II.

THE PHYSICAL HISTORY AND GEOGRAPHY

OF

LAKE PONTCHARTRAIN,

AND

ITS CONNECTIONS WITH THE MISSISSIPPI RIVER AND THE GULF OF MEXICO;

WITH A PLAN FOR ITS IMPROVEMENT, INCLUDING A METHOD FOR THE CONSTRUCTION OF CHEAP AND PERMANENT BREAKWATERS FOR THE PROTECTION OF HARBORS WHOSE BEDS ARE SAND, CLAY, AND OTHER FRIABLE MATERIALS.

PART II.

THE IMPROVEMENT OF LAKE PONTCHARTRAIN.

The health and commercial prosperity of all the Delta of Louisiana, north of the Mississippi River, and below Baton Rouge, depend upon the reopening of Bayou Manchac. The deepening of the two entrances to the Gulf, Chef Menteur and the Rigolets, and a lake harbor, all deep enough to admit ocean vessels of a large draught through the Mississippi Sound to New Orleans and to Baton Rouge, can only be effected by the improvements planned in this essay for this bayou and Lakes Maurepas and Pontchartrain. The overflows of the lower coast and of the whole Delta will be prevented if a proper system of levees, protected by angulated jetties connected with them, is applied—the jetties always to be constructed above the caving banks to deflect the bottom current of the river from them, and to deposit batture against them. Without these improvements for this bayou and these lakes and their outlets, no plan for the sanatory and commercial welfare of New Orleans will be complete. The cost of the whole plan will be less than $1,000,000.

This beautiful lake, although it lies within the limits of the State of Louisiana, is, I suppose, the property of the United States by the same title which gives it the ownership of the Mississippi River. The cession of Louisiana to the United States by France conveyed with it this great river and all its navigable tributaries, and the lakes connected with it and the Gulf of Mexico, which are waterways of commerce. These "public highways" and commercial avenues, in which all the people of the United States are interested, have never been relinquished by the General Government to this State. As the ownership of this lake and its connections with the great river and the sea is vested in the United States, it is the duty of its Congress, for the "general welfare" of the people, to make all the improvements which the necessities of commerce and other objects of public utility require. National justice demands that this should be done for this river and lake, and for all the avenues of travel and traffic leading to New Orleans, with the same liberality and for the same objects as appropriations of the public money have been made for the improvement of the harbors of Boston and New York. Even if the city of New Orleans or the State of Louisiana were in a condition to undertake the work of hydraulic engineering necessary to be applied, and which our highest interests so urgently demand, the consent of the Government of the United States through an act of Congress would have to be obtained. Even in the application of the plan of drainage which I have recommended, and which the health and commercial prosperity of New Orleans require the city to execute immediately, such an act of Congress may have to be obtained. To make the drainage of it effective, the Bayou Saint John and the canals and basins of stagnant water should be drained.

I have been informed by some of our most eminent lawyers that the right of property in the Bayou Saint John is clearly vested in the United States. At the period of the purchase of Louisiana from France this bayou was an important commercial waterway; and when New Orleans was a fortified village it was considered indispensable to its prosperity, but now that it has grown to be a great city, it has become a nuisance and an offensive generator of malaria. If an act of Congress is necessary it ought to be obtained immediately, in order that this stinking cesspool may be drained and dried as soon as possible, and its bed transformed into streets and lots for buildings and gardens. All the other receptacles of filth and putrid water, the canals and basins within the city and its environs, ought to be destroyed and their commerce transferred to the shore of the lake and to the lines of railroads terminating at its wharves. The city authorities should lose no

time in abating these nuisances, which are the principal causes of our epidemics and malarial diseases, and, as such, the main hindrances to the growth and prosperity of this metropolis. If our representatives in Congress will do their duty, it will not be impossible, or even difficult, to get the General Government, of which as the representatives of the people of Louisiana they form a part, to make all the appropriations of money necessary to improve Iake Pontchartrain and its necessary connections with the Mississippi River and the Gulf. It is certainly the duty of the United States to do this.

THE IMPROVEMENT OF LAKE PONTCHARTRAIN.

In 1814 this lake received a very large supply of fresh water directly from the Mississippi River through the Bayou Manchac. This bayou left the river opposite *Manchac Point*, about 12 miles below Baton Rouge, and after coursing along near the high and beautiful hills which are the escarpments of the fertile alluvial "bluff-formation," upon the plateau of which are built Natchez, Vicksburg, Memphis, and other fine cities, it discharged its muddy waters into Lake Maurepas, distant from its head on the Mississippi on an air-line about 32 miles. But it reached its mouth in this lovely lake after meandering at least a hundred miles through recently formed alluvial lands of inexhaustible fertility, and near the more elevated plateau of the bluff-formation crowned with grand primeval forests of beech, magnolia, and all the finest trees of the southern woods, and dotted with the multiplying settlements of thrifty planters. On its course it received the waters of the pure and bold Amite, which rises in the pine forests growing upon the barren sands and pebbles of the glacial drift which supports all the vast pitch or long-leafed pine woods of the South, which peculiar soil of variable depth overlies all the lower surface-depressions of the tertiary, and furnishes the exclusive food of this valuable tree, which does not grow indigenously upon the tertiary, or any older formation which "crops out" through this diluvial "orange sand" deposit. This water-worn and discolored detritus of the post-tertiary glacial flood which poured over North America from the Arctic Ocean is widely strown over all the Gulf States, and covers all the upland areas of Mississippi, Louisiana, Alabama, and parts of Texas, Arkansas, West Tennessee, and Florida, no matter what may be the denuded formations lying immediately beneath it. But it is the *general surface* of the tertiary formation of the Gulf States, and the only land upon which the forests of the long-leafed pine are found. The Amite and its numerous tributaries flow out of these pine lands and through the far more fertile bluff-formation upon which no long-leafed or other pine grows spontaneously. This is a recent deposit which *overlies* the glacial drift. It was formed by a local deluge or the drainage of one of those post-glacial seas, such as existed upon all the continents, and were drained in a subsequent epoch, and either synchronously or successively in times not very distant from our present era. The particular fresh-water sea, whose drainage formed the Delta of Louisiana and much of the flat coast-lands of Texas, and all the bluff-formation of the States of the valley south of the Ohio River, existed between the Rocky Mountains and the Appalachian chains, and the older connected and denuded sedimentary rocks of the Ozark and Cumberland, which before their disruption and severance formed the southern shore of this mediterranean sea, whose northern limits, penetrated by the McKenzie and other Arctic rivers, have not been explored. It was certainly drained by the Mississippi River, which, after tumbling for ages over a great water-fall above Cairo, whose marks are seen upon the lofty cliffs on both banks, cut its way up towards the upper part of the rim of this great sea by a process of erosion similar to that by which the Niagara is trenching its chasm towards the depths of Lake Erie at Buffalo, where its falls will inevitably disappear, and with them Lake Erie will also vanish and destroy Lake Ontario, and transform the Gulf of Saint Lawrence into a delta, and exhibit all the phenomena on a smaller scale displayed in the Mississippi Valley when the great sea, whose remains are the lakes Superior and others left in the deepest depressions of its bed, poured its waters and their wrecks into the Gulf of Mexico at Baton Rouge, and formed the vast area of the coast-lands and swamps of Louisiana, and the high plateau of alluvial bluffs, crowned with rich plantations and magnolia forests.

But this digression is more suitable to a geological dissertation than to an essay on hydraulic engineering for the improvement of Lake Pontchartrain. I would not have made it if it were not

written to be read by members of Academies of Sciences, as well as by illiterate engineers and politicians. I will say no more in regard to the physical geography of this lake and its principal affluents through Lake Maurepas, except that *these lakes and Bayou Manchac are the shrunken remains of the most eastern and northern mouth of the many mouths* of this mediterranean-sea river when it flowed in the zenith of its grandeur, and entered the Gulf from the Sabine to Pearl River by hundreds of embouchures, some of them wide as Vermillion and Barrataria Bays, and the whole volume of fresh but angry water, a hundred miles wide and 600 feet deep, rushing from Cairo to the sea, presented the appalling spectacle of a river compared with whose gigantic size and strength the magnificent Amazon in the periods of its grandest floods is but a pigmy rivulet. In 1814, ages after the drainage of this sea had been effected through these great mouths, and such climatic changes had occurred that the mammoths and many of their pachydermatous associates died, the Mississippi pined and withered away, until it could no longer fill its great southern mouths, and preserve the vast delta it had thrust into the Gulf a hundred miles beyond the present shore of Louisiana. It at length became too feeble to force its way into the Vermillion, and the other mouths it had made in the days of its manhood's prime when it filled up the whole alluvial area with logs, brush, sand, and mud, and all the materials of the lands its deluge had engulfed from the mediterranean sea to the ocean. It could not flow in its feebleness through these wood-bound barriers which it had buried, in the plenitude of its strength, several hundred feet deep. It was compelled to leave its direct southern course from the pole to the equator, at Baton Rouge, and flow through its northeastern mouths carved through the yielding *tertiary* sands and marly clays. Only a few little remnants of its ancient channels, much obstructed by logs and buried wrecks of all kinds, were occupied by the Atchafalaya and smaller bayous leading from its right bank to the remnants of its mouths in the Gulf, where all its delta has long been abandoned to the erosive action of the tropical Gulf-Stream current, which has swept away more than half of its original formation, and lowered the Mississippi to its present level.

It is now faintly and vainly struggling to extend its alluvium far out of its normal direction to the east. In 1814 Bayou Manchac was the sole representative of its ancient northeastern outlet. It was then and is now a very necessary carrier for the products of the fertile "bluff" plantations at whose base it flows, receiving the Amite which intersects the prolific plateau; and it is also much needed for the commerce of the rich alluvial lands which for a hundred miles line its banks. When General Jackson came from Tennessee, in December, 1814, to defend New Orleans against the formidable force sent by Great Britain to capture it, and to conquer and hold with it the whole valley of the Mississippi to connect it with her West Indian and Canadian possessions, he found Bayou Manchac a deep and broad navigable stream, which the British had thoroughly sounded, and through which they had determined to pass gunboats drawing from 7 to 12 feet water, to cut off his supplies from Kentucky and Tennessee, and attack him in the rear, and closely besiege him, encircled in the city by their naval and land forces without the possibility of his relief. This wonderful man had never heard anything about *jetties*, *mattresses*, or *caissons*. I doubt whether he understood the definition of a dozen technical terms of military or civil engineering, and I am sure that he knew nothing that any books could have taught of hydraulics. Such things had not penetrated the pine woods of the Carolinas, nor the wild woods and canebrakes of Tennessee and the Creek Nation, where he had spent his life before he came to defend this recently-formed *semi-aquatic spot of earth* against the most thoroughly educated and the bravest and best disciplined troops in the Old World, and who had just conquered the Old World's conqueror. He had read no books on hydraulic engineering. He needed no information which they could give him. He had seen axes fell trees, and he had seen the beavers cut them down with their teeth, and make dams with them which would guide the course of rivers, or obstruct their channels entirely with scientific works which no floods could remove. He had the divine gift of genius, and the rare but invaluable talent of common sense, and with the faculty to learn from observation and experience, and guided by the unerring instinct of the beavers, the perfect hydraulic engineers of the God of nature, he blockaded Bayou Manchac with trees and *beaver brush-work* so effectually that he rendered it useless to the British, and, unfortunately, to the planters and merchants also. In fact he almost obliterated that mouth of the old Mississippi from the face of the earth. By his original feat of hydraulic engineering he rendered abortive the British naval victory on the lake, and he saved New Orleans; but the effect of his successful work has been for sixty-

three years most injurious to the commerce and health of the residents near the bayou and its tributaries, and around the shores of Lakes Maurepas and Pontchartrain, and it has been very detrimental to the city of New Orleans.

Before General Jackson closed it, a large volume of fresh running water was discharged by it into Lake Pontchartrain. This had been thoroughly clarified by its passage through Lake Maurepas. After winding around Jones's Island it flowed into Lake Pontchartrain at the Choctaw Village by a single mouth. The volume of pure water from it so filled the lake that it gave it a strong current toward the east along its shores, quickening the currents of the Tangipahoa and Tchefunctee Rivers, and of the navigable Bayous Lacombe, Vincent, Saint John, and all the smaller streams emptying into it; and at the same time, while adding to the health of its shores by improving their natural drainage, it deepened the outlets of the lake to the Gulf through the passes Chef Menteur and the Rigolets.

The first improvement I would suggest for Lake Pontchartrain is, to *reopen Bayou Manchac*, and to utilize it for irrigation, drainage, navigation, and all the beneficent uses to which running water can be applied. As it was closed by the United States, whose power was skillfully but arbitrarily wielded by the greatest of its generals, the damage of more than half of a century, and which it is difficult to estimate, ought to be promptly and liberally repaired at its cost.

The next improvement I recommend is *to utilize the Bonnet Carré crevasse.*

The cause of the *opening of this crevasse was the closing of the Bayou Manchac.* Whenever a natural outlet for the relief of the flood water of the Mississippi is closed, the overburdened volume will relieve itself by a crevasse which it will burst through some weak point in its natural or artificial banks. It generally selects some caving bend the nearest to the outlet or mouth of the channel which has been rashly closed in opposition to the law of its natural hydraulic system, and which the wisdom of the ancient aboriginal mound-builders and agriculturists of its valley taught them to regard with sacred veneration. Instead of closing *these safety-valves for the escape of the flood-waters*, in order to save themselves from inundation, as some thoughtless engineers advise us to do in regard to the Atchafalaya, Lafourche, Plaquemines, Yazoo Pass, and others, they carefully opened them all, as did the ancient Egyptians to control and utilize the floods of the Nile. Acting upon the hints which bountiful Nature had given them, and guided by its wise and beneficent directions, they not only enlarged, deepened, guided, and carefully leveed all these natural outlets, but constructed many others for the various useful purposes of navigation, drainage, and irrigation. No physical geographer with ordinary capacity for observation can doubt this who will carefully examine the vast net-work of bayous connecting the Mississippi and the Yazoo, and see the powerful levees they built yet standing covered with the tumuli and all the remains of the extinct millions of this enlightened but vanished race, abundant as those which were constructed by the subjects of the ancient Pharaohs, and which gave to the Yazoo Ok-Hinna, its Indian name, which in the languages of the Choctaws and Chickasaws means "the River of Ruins."

The connections of the White, Saint Francis, Washita, and Red Rivers with the great River and the Gulf all prove the same instructive theory to be correct. The Nile was once an unbridled and shifting river, which, from the cataract of Syene to its mouths in the Mediterranean Sea, flowed through swamps, natural bayous, and lakes, and overflowed them all, until Menes and other wise monarchs bridled and controlled its waters with canals, aqueducts, and leveed lakes, natural and artificial, in the manner described by Herodotus. All these were used for three purposes—the prevention of overflows, drainage and irrigation, and navigation. When the Nile was dangerously full, and the land was threatened by it with a flood, after impressive ceremonies, some of which are yet observed and conducted by the modern rulers of Egypt, the water-gates at the head of each canal were opened, and the fields were all irrigated, and the dangerous water was made propitious to the soil, and then permitted to flow by many outlets to the sea. Lake Mœris, 30 miles long and 6 miles wide, leveed and guarded by water-gates placed upon all the inlets and outlets of the great aqueducts connecting it with the Nile and the sea, was filled. When the flood had spent its force, and the work of irrigation was accomplished, the gates were closed, and the water of this and all the other lakes and artificial reservoirs was retained and held at a level high above that of the valley fields, to furnish any deficiency of water for irrigation the next year, if the annual rise of the river was not sufficient to supply the wants of agriculture.

I therefore object to the theory of closing the bayous, for these unanswerable reasons: First, they are necessary for the inland commerce of the valley, because they furnish the cheaper means of transportation; second, they afford the best and only means for draining and desiccating, and then for irrigating all of its swamp-lands remote from the Mississippi; third and finally, they may be made to save the valley from overflow, as the opening of the Bonnet Carré and other crevasses and the bursting of the levees of the upper coast saved New Orleans from the May flood of 1874. Our true policy is to jetty the main river with converging brush and crib work to give fixedness to its channel and deepen it by erosion, and to open every outlet and utilize it for commerce and agriculture.

Instead of closing Bonnet Carré crevasse, I think a ship-canal ought to be made of it about 8 miles long and 200 feet wide, with a depth of 6 feet below the lowest water-level of the Mississippi, and it should be run upon an air-line due north into the southern margin of Lake Maurepas. It should be properly shielded and guided with jetties at its outlet from the Mississippi to prevent it from enlarging its channel, and also at its entrance into the lake to hinder the formation of a bar. This canal can be used for navigation and the drainage and subsequent irrigation of 64 square miles of marsh-lands adjacent to it, now worthless for agriculture, but which it will make equal in fertility and value to any in the State. The large accession of water which this Bonnet Carré Canal and the reopened Bayou Manchac will give to Maurepas will make a strong current in this lake to the east and through the Jones's Island Pass into Lake Pontchartrain, and through it into the Gulf. The current will be a continuation of that of Bayou Manchac, which, although it will be swift and deep, will be easily controlled by jetties of piles and fascines of felted brush. There will be but little current in the canal, as there would be if its course were south or even east, and it will need no lock.

Many years ago I discovered, and ten years since I demonstrated in a lecture to the New Orleans Academy of Sciences, that the cause of the velocity of the current of the Mississippi was not its *fall*, but its *course from north to south; or the centrifugal force which it receives from the earth's revolution upon its axis;* and which force propels all fluids upon its surface from the poles towards the equator, and retards their centripetal flow from the equator towards the poles. It is this force which makes the earth an oblate spheroid instead of a sphere. It causes its equatorial diameter to be about 27 miles longer than the polar. It elevates the tropical oceans under the equator 13½ miles above a globe level. It causes the cold centrifugal ocean currents to flow out from the poles towards the equator, *side by side* in the temperate zones, but opposite to the Gulf Stream, the Kuro Siwoo, and other centrifugal currents which rise in the torrid zone above them, and seek their level by running to the poles, where they are metamorphosed and merged with them by the cold of the frigid zones. This force, which *retards* the currents of the La Plata and the Nile, whose course is directly *opposite to that of the Mississippi*, and which flow *from the equator towards the poles*, will act directly *against the current* of the Bonnet Carré Canal, and give it a gentle descent into Lake Maurepas.

The third improvement I recommend for Lake Pontchartrain is *a jetty of piles and felted fascines at the mouth of the pass at the Choctaw Village.* This should be shaped like a V, with the point meeting and dividing the combined waters of Lake Maurepas, and directing their currents around the shores of Lake Pontchartrain to its two passes into the Gulf. The effect will be to form a large, beautiful, and perfectly healthy island at the upper end of the lake, upon which a *star-fort* can be erected to guard this important inlet. Hotels, hospitals, and buildings of all kinds can be built upon its healthy and airy site. It will enlarge its area slowly and continually, while the currents eddy around it, and deepen near the shores. These currents should be utilized for harbors a half mile wide, made by breakwaters of piles and brush fascines a half mile from the lake shore and parallel with it. The materials dredged to deepen them next to the shore, for the convenience of wharves and the motions of vessels of all kinds, should be used to construct a high and broad levee to protect the city and plantations from the storms of the lake. Intervals at least 200 feet wide ought to be left in the construction of the breakwater, at distances of two miles, for the passage of vessels. This breakwater, harbor, and levee may be extended as the growth of the city or of several cities and multiplying villas and plantations may require, until the improvements embrace and encircle the entire lake and all its connections with other waters. This with the aqueducts and canals will encompass New Orleans with a sanatory cordon of pure running water, which will shield

it against the ingress of all malaria generated *outside* of its limits. Malaria, like the mythical witch of Scotland which chased Tam O'Shanter from Kirk Alloway to the Doon, *cannot cross running water*. Residences upon islands surrounded by river or ocean currents, if their sites are kept clean from local filth, are usually very healthy. The use of drainage is to prevent the origin of local or indigenous malaria. The *yellow-fever* poison is probably a *tropical plant*, of the *fungus family*, to which the *mushroom*, *lichen*, *alga*, and all the *moulds* belong. This exogenous and imported poison will spread wherever there is heat and moisture to nourish it, and it can only be excluded by rigid quarantine. It originates in tropical filth, but, like the small-pox or itch, whether it is a minute *aterous* or wingless insect, or the spore of a microscopic fungus or other cryptogamous plant, nourished first in some filthy hovel of the torrid zone, it will poison the cleanly inhabitants of all cities of the temperate zones at a less elevation than 1,000 feet above the sea.

The first beautiful effect of the application of this plan will be seen when the breakwater is constructed a half mile in front of the termini of the Lake-end and Pontchartrain Railroads. The cyclones will dash the storm-waves against them, and roll them through the gateways of the ships and scour out the passages; but they will disperse their force harmlessly in the wide and quiet harbor, and never strike the shore; while they will transform the breakwater into a long line of islands made by the sand and shells thrown up by the tempests, and which will bury the piles and fascines out of sight. But the materials of which they are formed, and especially the willow, cypress, and other trees of the swamps, will grow and form a lovely display of living green. In the course of a few years these islands will make smooth and broad sand-beaches towards the center of the lake, and form crescents of semi-tropical lands parallel with the entire encircling harbor and shore, more beautiful than the lovely ring-shaped atolls of the Pacific Ocean. They will be crowned with bath-houses, hotels, and residences of merchant princes and planters, displaying all the varieties of convenient, chaste, and gorgeous architecture, and ornamented with all the fruits and flowers which will grow in our almost winterless clime. The glories of Chalco, Tezcuco, Como, and Maggiore will be eclipsed by the variegated pictures of elysian loveliness and magnificence which the future will display upon the bosom and around the shores of Lake Pontchartrain if this plan for its improvement shall be adopted and faithfully applied. The commerce of a city greater than ancient Rome will float upon its surface, and the millions of its inhabitants will find healthy and profitable employment, while they will be refreshed and invigorated by its purifying waves and balmy gales.

PART III.

AN EXPLANATION OF THE PRINCIPLES UPON WHICH THE PLAN FOR THE CONTROL AND UTILIZATION OF WATER-CURRENTS IS BASED,

AND ITS APPLICATION TO

THE MISSISSIPPI RIVER,

CONNECTED WITH A

GENERAL LEVEE SYSTEM.

A GENERAL PLAN FOR THE IMPROVEMENT OF ALL RIVERS AND HARBORS BY THE PROPER GUIDANCE OF MARINE AND FLUVIATILE CURRENTS TO ERODE CHANNELS, TO FORM NEW LAND, AND PREVENT INUNDATIONS.

INTRODUCTORY.

Unfortunately all attempts made and levee systems applied to control the Mississippi have been superficial. They have no reference to *the bottom current.* If that is neglected levees cannot be protected, and crevasses by undermine cannot be prevented. The channel of the Mississippi can only be deepened, bars can only be removed, levees can only be guarded, and overflows can only be averted by controlling and guiding properly this bottom current; and that cannot possibly be done by any other mode than by jetties constructed upon the plan recommended in the following essay.

The levee system properly applied to the whole river from New Orleans to Saint Louis, provided that the jetties recommended are applied to the lowest bar first, and then successively to each of the others above, and also above the concavity of each bend of the river, and connected with the top of the levee and the bottom of the river, will cost less than $10,000,000.

THE OUTLINES OF A PLAN

FOR

Controlling the Mississippi River so as, first, to guide its current and protect levees; second, to save its banks from undermines; third, to make batture, or alluvial deposits where they are needed; fourth, to remove its bars without dredging; and fifth, so to deepen its channel by erosion as ultimately to prevent overflows.

The main objects of the plan are to give permanence to its banks, and to prevent the shifting of its bed; to preserve its islands and its shores with all the property upon them, and at the same time to make it navigable, at the lowest stage of its water, to ocean vessels of the largest size.

This plan was elaborated many years since, presented to the New Orleans Academy of Sciences in 1866, approved and adopted by it January 8, 1868, and sent to the various Academies of Sciences of America and Europe during that year.

This plan has been very generally approved, but the most useful principles of hydraulic engineering embraced in it, especially the proper *angulation* of the jetties with reference to *the artificial current-channel* intended to be formed by their guidance of the *natural current*, has never so far been applied either in America, Europe, or elsewhere.

The plan is based on these two principles—

1. The *angle of reflection* of water in motion is equal to *the angle of incidence* minus the resistance. (See Plate I, Diagram 1.)

2. The walls of all jetties for controlling water, where their foundations are mud, sand, and other friable materials, or where they do not rest upon rock, or *undisintegrable materials*, must be made of brush, *latticed-diagonalized-cribwork*, or other non-reflecting substances; or so faced with such materials as to break and dissipate the force of the currents they are intended to control by hurling the particles of water which compose them against each other, and preventing their downward reflection, and consequent undermining action. None of the surfaces of the materials should be smooth, but crossed, or corrugated. A simpler and more comprehensive description of these controlling or guiding jetties may be given as follows: *They are properly angulated reflecting walls faced with non-reflecting materials.* Wherever it is applied it should control the bottom currents.

I.—THE MATERIALS FOR THEIR CONSTRUCTION, AND THEIR FORMS.

(See Plate III, Diagram 1.)

These may be varied to suit the localities intended to be improved and the depth of the water in which they are to be used; but none should present plain surfaces.

1. To control currents too deep for their beds to be reached by piles, and where it is desirable to guide the bottom currents, especially those of the Mississippi, at depths of from 40 to 180 feet, or at a greater distance below the surface, they should be made of strong cubical-formed diagonally-latticed caissons filled with loose stones, of convenient size for handling, and for being anchored, and linked together in a row or in rows upon the beds of the deep bottom currents; or they should be made of *felted fascines* strongly bound and heavily ballasted to resist the first shock of water-logged stumps, trees, and bowlders of clay, or other heavy substances hurled against them by the bottom current, and which may remove them from their alignment and connection with the portions of the jetties in the shallow water, constructed of piles and fascines, and of which these heavy cribbed caissons are intended to be the *termini* in deep water. (See Plate III, Diagrams 10, 11, and 12.) The diving-bell should be used, to see that they are compactly adjusted on the deep bottom to form an obstruction to catch and compact the silt and deflect the current.

2. For all shallow water in our soft-bottomed rivers, and the mud and sand bedded lakes, bays, and estuaries, the jetties ought to be made of piles and brush fascines—materials which grow in every swamp and bottom-land forest. The cypress, tupelo gum, swamp ash, and other watery growths, and the tall young willow and cottonwood saplings, which form the winter "towheads" of the recently-formed areas of batture, and line the margins of all the bayou and river banks, invite their use. No rock is needed for the construction of these *shallow-water jetties*. They should be made as follows:

Two rows of piles 12 feet apart, the piles in each row 8 feet distant from each other. Each pile to be made of a stout tree with *the bark to be left upon it*, and the rougher and more corrugated the better it will answer the purpose as a non-reflector in resisting the undermining action of water. The pile should be properly notched at the *lap* or *upper* end to receive the attachment of one or two *girders* or connecting poles, and sharpened at the *butt* or root end into a *triangular* or *quadrangular* point to be driven easily and to a sufficient depth with the *butt downward* (see Plate III, Diagrams from 1 to 7), in order that it may stand firmly when the currents make deposits around its base. It will then be placed on the principle of the obelisk and in the natural position of the tree. The fascines should be made of bushes as straight as possible, 15 feet long, and each one should be fastened with two *wraps* around four stout sticks radiated at right angles to the saplings or switches of the fascine of which these two circles of radiated sticks form the frame. Each stick should be barbed at one end and sharpened at both ends. It should be cut below a stout limb at least an inch thick, and this limb should be shaped by the hatchet into a barb. The points of these sticks should project at least a foot beyond the sides of the fascine. The wraps should be far enough apart to prevent any hindrance to convenient carriage upon the shoulder, and their dimensions should not be too great for the strength of an ordinary man to handle them. They must be 15 feet long in order to project at least 18 inches beyond the lateral lines of the rows of piles, between which they should be packed in alternate floors or layers at right angles to each other, and then rammed and felted together with a heavy and properly constructed *brush-packer*. (See Plate IV, Diagrams from 7 to 11.) The object of the barbed wraps is to make them hold to the bottom when driven down upon it, and to fasten *like felt* to each other when packed together, and to obviate the use of stone to weight them down.

After the space between the piles is thoroughly filled, the whole work should be girded together by 15 and 24 feet willow poles spiked into the notches mortised near the top of the piles; the 15-foot poles crossing the line of the breakwater or jetty at right angles, and the poles 24 feet long crossing these 15-foot poles and each other diagonally on the central line of the top.

These breakwaters will resist the storms of the Gulf, and form the *nuclei* of islands and sand-spits. They are buried in mud and sand, and will grow where they are planted and display living lines of willows and cypress, and the usual growth of our marsh-lands. I recommend these structures as the strongest, cheapest, and most permanent breakwaters and jetties for all our southern sea and river hydraulic defences. Nothing will be found superior to them for stopping crevasses. I suppose that the work will be faithfully executed, and its character may be greatly varied. I only recommend it for water less than 40 feet deep. They are not only cheaper than iron, but more durable.

II.—THE LOCATION AND PROPER ANGULATION OF JETTIES.

I. No jetties intended to control water-currents, to deepen, and at the same time to make permanent channels, of regular forms, and without the aid of dredging, ought ever to be made *parallel*, for these reasons (see Plate I, Diagram 5):

1. Although parallel jetties may be made to guide and to confine a current, they will not *accumulate* or *double* its erosive force by reflection from each wall, or from both jetties upon a given line, so as to form a channel of a regular and uniform shape and depth. The globular particles of water between parallels move along *parallel lines* until they strike some obstruction to their motion which will deflect them upward, downward, or laterally at angles given by its shape. A sunken ship in the channel or a rounded stone or mud-lump will part the current and hurl it with dangerous undermining force against both jetties. At the mouths of rivers, and especially at the passes of the

Mississippi, into which vessels entering meet those which are departing, they often collide and sink. The prow of the sunken vessel points up stream while the stern is turned seaward by the current. The currents parted by its prow are deflected with erosive force against the jetties and cut deep troughs. The eddies whirl behind the stern and meet and mingle, forming obstructing lumps, bars, or islands. Clusters of trees tied together with vines, drifting seaward, and anchored by their limbs or roots, or huge bubbles of clay lifted by vast volumes of gas generated by hammocks of logs, brush, leaves, and other vegetable matter buried deeply in the strata of the ancient Delta, produce similar effects. A large water-logged tree-trunk three or four feet in diameter, or a ship sunk near one jetty and lodged angularly to the current, will deflect its whole force against the other, which in turn will be reflected diagonally in a contrary direction, and give it a *zigzag course from wall to wall* for a distance of many hundred yards, or miles, proportioned to its velocity and the angle of the deflecting obstruction. Then the obstruction can only be removed by blasting dredging, or other mechanical force; and the channel can only be straightened and deepened by the scraping or spading of the pump, dredge, or other expensive artificial contrivance. The cross-sections of soundings below such obstructions across the parallel-jettied channel exhibit irregular curves of various kinds, and reveal a trough, shaped very awkwardly, difficult and dangerous for navigation. These facts are so obvious as to make unnecessary even these simple diagrams for their illustration. (Plate I, Diagram 5.)

Properly converged jetties reflect the water at angles corresponding with their angulation. They converge the water and accumulate it into an erosive current *continually acting* with a cork-screw, drilling, and boring motion, cutting, with the combined power of the auger and sand-blast, upon a fixed line as permanent as their position. This current, always moving upon a friable bottom of mud, sand, tenacious clay, or even disintegrable chalk or sandstone, will bury in it or remove from it any object whatever. It will cut away mud-lumps and islands, float off any wooden or other buoyant obstacle, and by excavating the fragile bottom, guided downward by the reflecting sides of an iron ship or block of stone, it will bury the solid and heavy obstruction and shape the bottom of the channel in a form corresponding with every other part of the trough excavated by the guidance of the angulated and converged jetties. (See Plate I, Diagram 4.)

2. Parallel jetties cast no accumulated erosive current beyond their points. The water which runs through them is immediately diffused and spreads out in all directions. They are as unscientific as cylindrical tubes attached to the ends of the hose of fire-engines for throwing water. *They scatter well, but will not squirt far.* Pipes like *inverted cones, sections of which are the lines of converging jetties,* propel the water much farther with concentrated erosive force, and will form an eroding current which will remove obstacles far distant beyond their extreme points. (See Plate V, Fig. 1.) Within the banks of rivers batture will always form between their points and the banks, and against the banks along their curving bends at distances below their points proportioned to their angulation and the velocity of the current. At sea, upon shallows where it is necessary to connect their angles throughout their extension to guard them against the ordinary currents and the more violent action of those produced by storm-winds, which would break through them if they were disconnected, cut trenches across the artificial channel, and fill it with sand on either side of the gaps; if they are properly constructed the batture will fill up only the angles and leave a trough open with its sides parallel and aligned with their points, while vast areas of land will be formed on each side of them from their points to the mainland.

II. *Jetties should never be located at right angles to the current, or to the line of the bank of the river they are intended to protect*, for these reasons:

1. Although such jetties *confine* a river or sea current and give it a greater depth, they do not *guide it* either above or below their points. The central current flows directly on at right angles to their lines. The left and right flanks of it strike the jetties perpendicularly. Their under currents checked are thrown up and down, and excavate their foundations if they are smooth; or if they are latticed, corrugated, or made by other means non-reflecting, they accumulate deposits against them, and spread out laterally. One portion acts directly against the whole volume of the central current which whirls it against the bank below the jetty and excavates at the same time the bottom below the foundation of the jetty-point, and the other portion above is thrown directly against the bank and undermines it, and destroys the connection of the jetty with it. Unless addi-

tional works are constructed giving the fastening of the rectangular jetty to the bank the form of the letter T, a portion of the river will cut off its connection with the bank, pass through the gap, and form an island of which the jetty will be the nucleus or frame-work, and one of its diameters. This reveals two other objections to this angulation of jetties already stated.

2. The rectangular jetty, requiring one or more extensions L or T at its base or connection with the shore is too expensive; and if these additional works are not constructed to secure the land from *undermine* and submergence it will make *crevasses* and swamps; and it is,

3. *Dangerous* as well as *worthless.*

I have heard these arguments urged in favor of this plan of rectangular jetties:

1. The rectangular jetty is less expensive than the diagonal, or the deflector, or converger, which are different names for the same thing, because it is one of the *short* lines of a right-angle triangle, while the *diagonal* is its *longest line*, or the *hypothenuse.*

To this I answer that *the entire hypothenuse* of the rectangular triangle need never be used on the Mississippi River or elsewhere to protect the banks, to make batture, to remove bars, or to deepen channels by removing other obstructions. *Only a part of this line properly angulated* is necessary for the construction of the jetty. Its length will be proportioned to the width of the river and the depth of the water, and the distance of the bottom current from the bank. Where the river is the widest the jetties should be the longest; but in such places the current is the weakest and the water the shallowest, and consequently the jetties may be made in the least expensive manner, and they will cost less than short jetties in deep water flowing with swift and strong currents, and which will require heavy and expensive mattresses or caissons for their construction, while these long jetties, to confine and guide the water to make it erode deep channels across bars and shoals, can be built of cheap piles and felted fascines without the additional expense of stone or iron, so as to be as strong and durable as the most permanent works of man. (See Plate IV, Diagram 3.)

2. It has been said in favor of rectangular and parallel jetties that Sir Charles Hartley removed with them the bar at the mouth of the Danube. This is a mistake, as will appear from the following diagram of his work. After a survey of the Danubian mouths in 1829 various efforts were made for deepening the bar of the Sulina mouth, which was deemed the most practicable, and which had a natural depth of 10 feet. The useful idea occurred to the engineers as early as 1857, that if the water could be confined to the ordinary width of the river above its delta, its current would erode a channel across the bar at least equal in depth to that which it maintains between its natural banks for a great distance above its outlets into the Black Sea. It was also correctly inferred that there would be no extension of the bar beyond the jetties, because a sea current from the north passes from the east by the Crimean coast against the western shore, touching the mouths of the Danube, and flowing into the Mediterranean through the Bosphorus, the Sea of Marmora, and the Hellespont. In 1861, after numerous efforts had been made to effect this confinement of the water by rectangular jetties, it was determined to connect the works and to run two parallel piers nearly 600 feet apart entirely across the bar, and to force the whole volume of water of the Sulina pass to flow into the sea-current between them. The jetty-work with its extension was completed in 1871, and a depth of 20 feet was secured. But an examination of the operations which were at last successful will prove that the engineers did not understand the principle of converging jetties and their proper angulation. Their object was simply to confine the water between parallel walls, supposing that flowing through such contrivances it would dredge a regular channel of the required depth. The idea of a current deflected from a jetty converged from each side at a proper angle to the line of erosion, so as to accumulate an eroding current upon it, which, by its onward gyratory or auger-like motion, would cut out a deep mid-bank channel equidistant from the guiding jetties, seems not to have occurred to their minds; and many engineers of considerable reputation suppose that the removal of the bar was effected by the instrumentality of the *parallel piers.*

A simple inspection of the work demonstrates that the erosion was effected by a part only of the plan, where the principle of convergence was brought into action. (See Plate II.) The bar was removed by an accumulated converged current, produced by a small portion of each jetty where both were directed angularly or diagonally upon a part of the line of erosion. Fortunately

in connecting the upper ends of the jetties at X and W with the beginning of the parallels at Y and Z, their lines were converged, and although they were improperly curved and unequally angulated, instead of having been run straight and at equal angles upon the central channel line *c c*, yet they converged and doubled the force of the lateral currents on the line of the present navigable channel, *which they formed exclusively*, to the deep water of the sea. The only aid given them by the parallels was the protection they afforded as breakwaters against the storms and currents of the Black Sea.

The work of dredging or scouring out the channel was the exclusive work of the portions of the south jetty from *a* to *b*, and of the north jetty from *c* to *d*, which accumulated a gyratory eroding current all along the bottom of the present channel A A, which deviates widely from the line *c c*, intended for its bed.

I dislike to say that this happy effect was the result of the *accidentally* converged connection of the rectangular and parallel jetties. They certainly intended to connect them in order to confine the water and make it flow between the parallels planned to remove the bar, but I think the accumulated current which the convergence of the jetties produced, and which did the *principal part*, if not *the whole of the work of erosion*, was *unintentional* on the part of the engineers. I do not think they intended *the convergence* to produce erosion, because I have heard that they still recommend parallels for the purpose. The irregular winding channel AA which they made proves their ignorance of the whole theory of the proper angulation of jetties, and at the same time it demonstrates conclusively its correctness. If you will examine closely the diagram you will see that the navigable channel AA deviates from its proper midway course at H, and runs diagonally across it to the north parallel at I, which there deflects it eastwardly to J. The divergence given to the channel from its midway course at H, and its dangerous direction to I, is evidently caused by the erroneous angulation of the jetties X *d* and W *b*. The jetty W *b* converges towards the central channel line C C at a greater angle than that made by the opposite north jetty X *d;* and, consequently, *the line of erosion*, or the channel cut by the accumulated currents they produced, is deflected from H to I nearest to the jetty converged with the least angle toward the central line C C. This will be found by experience to be a rule without exception: *Jetties converged at equal angles upon a central line will cause the water-current which they guide to erode a channel, the deepest part of which channel will be upon that central line equidistant from both jetties. If one jetty is run towards it at a less angle than the other, the channel will be cut nearest to the jetty with the least angle.* (See Plate I, Diagram 2.) Consequently, a better plan for the construction of the Danubian jetties would have been to have constructed *two straight jetties*, in 1829, from the extreme northern and southern points of land at that time at *e e*, and to the points *f f* on the outer crest of the bar, and converged at equal angles upon the central line P P. Batture from the river floods would have filled all the spaces between the points of the jetties and their upper connections with the shores, and the lines, 600 feet apart, parallel with the central line of the channel P P; and the sands of "the stormy Euxine" would have extended its shores to the ends of the jetties and against their exterior sides.

It is best to *diverge two sea-walls* at angles equal to the angulation of the jetties from their extreme points. Nature, by its hydraulic system for removing bars and opening harbors at the mouths of great navigable rivers, indicates this plan as the best, and even gives us plainly the proper angulation for jetties, if we choose to imitate or assist her operations. I have heard it said that nature works with parallel banks to deepen the channels of water-currents. This is inferred from the fact that the banks of rivers, whether straight or curved, are usually parallel; hence the conclusion is deduced that in our efforts to remove bars and to deepen channels our guiding jetties or artificial banks ought to be made parallel. This would be true if the premise was correct; for a natural law is always our safest guide when we wish to effect by art what nature performs in obedience to the direction of the Great Creator by the physical forces He has given to her.

But the premise is false; for nature does not guide or deepen the currents of either rivers or seas with parallel banks. On the contrary, I safely and positively assert that *nature works with diagonal jetties exclusively to deepen all channels*, and makes their banks or lateral margins *parallel* by *diagonals* converged to the lines of the direction of the currents, whether they are fresh water or salt, fluviatile or marine. These natural jetties are formed of a variety of materials, rock, clay, wood, or

compounded detritus of various kinds, either undisintegrable by water or less friable and more tenacious and firmly fixed than the banks and bottom bars which oppose the currents which they direct against them. In rivers a diagonally-projecting rock is a natural jetty which will hurl the current against the opposite bank. If the bank which receives the erosive force is composed of strata of soft stone or of earth it will undermine it and wash it away. The Mississippi River, after it receives the Ohio, and leaves its cliffs of rock and enters its vast alluvial area which has all been stratified and rearranged in layers of sand, clay, or mixtures of both, by the floods, and the sleepless and tireless action of its "perpetual motion" for ages, is performing this operation before our eyes to-day of first destroying and then paralleling its banks by diagonal jetties.

Let us examine a single point on the right bank, from which descends a titanic current which strikes a curve in the left bank a mile below and undermines it and swallows it up with everything which grows or which is built upon it. Let us take this destructive, deflective, projecting point, and dissect, anatomize, and make a geological section of it. Its flat top is crowned with a forest of ancient trees and a jungle of cane and bushes, and a variety of vines tying and tangling all its vegetable growth together. Its slope to the water's edge is terraced usually with from three to five steps made by the annual inundations of as many years, marked by successive yearly deposits, the oldest covered with full-grown cottonwood and willow trees, and the newest with saplings and switches of the same growth; and upon the sand strown by the last rise and left bare by the receding flood, we find the downy seeds of these trees clinging to the newly-formed *batture* and springing into life. In time for the next vernal rise of the river they will have grown several feet in height, and covered the sand-bar as thickly as grass in the meadow or wheat in the field, ready to strain the mud from the water of the flood, and to elevate the terrace on which it grows to the height of the one above it. Beneath the water-level we find the sloping bottom of the point projecting diagonally, and all covered with pure sand down to the deepest depression of the river-bed.

Now let us cut through this angulated, guiding, and destructive jetty, and ascertain what is its core, nucleus, or foundation. We will find it at a depth of from 80 to 150 feet resting upon clay. It may be the wreck of a coal-boat, or some other vessel. Usually it will be a cluster of trees and bushes tied together with grapevines, bamboos, or creepers. The river undermines a portion of the primeval forest, and whole clusters of them bound together by vines fall into the water, and by the heavy masses of clay grasped by their roots they are sunk to the bottom where they are occasionally securely fastened, and by catching the water-logged brush, bowlders of rolling clay, and detritus of all kinds lodged against them and compacted into them by the bottom current, they form the foundation of a deflecting jetty which can never be moved. Even if the river cuts its way around one of these sunken tree-rafts, it usually leaves the mass as the supporting foundation of an island. Most of the islands of the Mississippi have been formed by these clusters of trees. Occasionally they float for a while after falling into the strong, deep current which erodes the bank; but where the river widens and shallows its volume over the areas of tenacious clay they "ground" and adhere to the bottom and form the *nuclei* of islands, which act the part of V-shaped jetties with their points *up stream*, which part and deflect the current and *cave in* and curve the opposite shores. Unless jetties are situated in such a position as to prevent the undermining action of these deflected currents, the islands will grow continually at the expense of the banks on either side.

These illustrations will be sufficient to show that the *river-currents* perform their work with diagonal and not with parallel jetties. *The parallel shores are formed by the eddies which whirl on either side of the eroded trough made by the converged and accumulated currents, and which deposit its excavated materials in lines parallel with its course. Sea currents also are operated by diagonals and not by parallels. Nature works with converged diagonal jetties in removing bars at the mouths of rivers, and also those between islands, or between islands and the mainland.* Ever since *the Noachian deluge*, or what geologists term *the Glacial epoch*, Nature has been striving to mingle the deep channels of the great rivers with the deep currents of the seas. This *alma mater* is not pressed for time in performing the work which God has given her to do. For nearly four thousand years she has continued this work with unerring wisdom and omnipotent power, and she has taught us how to aid or imitate her mode of removing bars by showing us that all these rivers enter the sea with *trumpet-shaped* mouths. The diagrams of the Saint Lawrence and each mouth of the Mississippi, and all other great rivers, prove this. They pour their waters into the great deep through divergent

shores, or banks which are natural-jetties diverged *seaward*, and converged *upward* towards the inner crest of the bars.

I call the attention of geologists and physical geographers to this important fact, which also deserves the careful consideration of all hydraulic engineers entrusted with the task of removing bars at the mouths of rivers. They not only enter the sea *trumpet-mouthed*, or with divergent banks, but the central line of their currents between the extreme points of land which terminate them is directed at right angles to the sea currents which they enter. Thus the mouths of the Danube open at right angles to the Black-Sea current, which flows from Odessa south across the Sulina mouth to the Bosphorus. The Saint Lawrence opens its vast jaws and discharges its huge volume at right angles into the great Arctic current which descends across it, and also across all the bays and river-mouths from Davis's Straits to Florida. The mighty Amazon, between divergent banks whose extreme sea-capes are 180 miles apart, pours its mammoth tide into the Atlantic current which flows from Cape Saint Roque at right angles to this giant river-mouth, and at the same angulation crosses the mouths of all the rivers on the coasts of the Caribbean Sea and Gulf of Mexico, as it flows on northwardly along the eastern shores of South, Central, and North America, between Cape Saint Roque in Brazil and Cape Sable in Florida, where it forms the Gulf Stream.

All the river-mouths of the whole earth demonstrate the same fact. I will now show the reason for this wise providential arrangement of these river-mouths and the sea-currents with which they mingle, and the operation of this wonderful hydraulic plan of nature to secure the beneficent object of removing the obstructions to the international commerce of the world. The proper study of it will convince any enlightened engineer that any obstruction at the entrances of bays and the mouths of rivers, made by shoals and bars, may be removed by assisting nature in the use of these marine and fluviatile currents, by the proper application of the hydraulic principles which she uses in connecting the deep channels of the rivers with the navigable currents of the oceans and seas. For the removal of all obstructions in bays like the Delaware, Chesapeake, Mobile, and others, the jetties ought to be angulated so as to utilize the scouring action of both the *flow* and *ebb* of the tides, and the influx and outflow of the storm-waters. This can be easily effected by constructing them upon the plan of the diagram for making a ship-channel between Heron Island and the mainland on the west of Mobile Bay. It resembles the worms of Virginia fences making a lane, with the angles of their panels opposite and equal. (See Plate III, Diagram 9.)

Another reason why nature has usually made the mouths of the great rivers and many bays open trumpet-mouthed, and at right angles to the deep-sea currents, is that their currents may be so checked that they may form safe harbors or easy entrances to vessels. If the current of any great river, like the Amazon or Mississippi, instead of entering one of these ocean streams at right angles, were mingled with it at an angle of from 11¼° to 45°, the *ekmuzesis*, or the suction of the ocean current applied to that of the river, would produce consequences some of which would be disastrous beyond our conception. Eroding velocity and contraction of its channel would certainly ensue, and there could be no safe and easy navigable entrance formed, such as now exists, for the admission of vessels. (See Plate V, Fig. 3.)

In order to show that nature uses this trumpet-mouthed form opened at right angles to these ocean currents to remove the bars of rivers I will take only one example to illustrate this fact. The Southwest Pass of the Mississippi will be sufficient for our purpose; and I select it in preference to the mouths of the Saint Lawrence and Amazon, because the bars once obstructing their outlets have long since been removed by their converging jetties, while the process of the removal of that of the Southwest Pass by the same instrumentality is yet in operation. (See Plate I, Diagrams 3 and 6.)

The mouth of this pass opens directly to the southwest and receives within its divergent jaws or natural banks the full force of the southwestern gales and thunder-gusts, and the great cyclones whose centers move to the northeast. The tides which enter it, and the currents which are driven furiously into it by the tempests, strike its banks which are converged upon the central line of the *inner crest* of the bar. Deflected upon it as they *rush in* from both divergent banks, they are converged and accumulated upon it, and loosen all its friable structure, which is carried out by the ebbing tides and the out-rush of the swollen waters heaped upon the inner crest by the storms; and

while a portion is borne into the ocean current and transported far away, the rest of the wreck of the bar is stranded on either side of the trumpet-shaped outlet, to extend the extreme points of land.

Above the bar the current of the pass pours into the deep trough cut by the concentrated influx of storm-water, and by its lateral eddies parallels the banks up to the new inner crest of the bar, which is advanced continually by the successive tempests and tides towards the deep tropical current of the Gulf which comes from the coast of Texas and Southern Louisiana after curving around Northern Brazil, Guiana, Venezuela, Central America, and Mexico, but whose eddies at the mouths of the passes whirl westwardly opposite to its eastward course. *All currents, whether of rivers or oceans, make eddies along the banks and shores which they erode, and which whirl as counter-currents opposite to the direction of rivers, and of the great equatorial and polar ocean streams.*

Ignorant of this law of all currents, whether of rivers eroding their banks or of oceans wearing away their shores, some of our hydrographic engineers have made it appear that the great tropical current at the mouth of the Mississippi flows westwardly towards Texas. They mistake the surface currents caused by easterly winds, and the eddying counter-current hurled upward by the warm Gulf Stream, which at a depth of several thousand feet is eroding the ancient rocks of the foundations of the continent as it flows on towards the coasts of Alabama and Florida. Vessels and boats *ascending* the Mississippi run next to the curving and caving bends of the river, because there they find counter-currents which bear them up stream; but they know that the river does not flow north but to the south in spite of these eddies.

To enable the Mississippi River and the tropical currents to finish in a year the work of removing the barriers between them, and which Nature unaided will effect slowly but surely in a few centuries, let us assist her a little, guided by the diagram with which she has illustrated her own hydraulic law, or rule of action.

Let us take the diagonal lines of the section of a trumpet, or truncated cone, which designate the natural banks or jetties of the Southwest Pass converged to remove the inner crest of the bar, and reverse their angulation and point them to the outer crest of it, and construct upon them our artificial jetties. Let them be made of piles and fascines as recommended in this essay. The water is all shallow from the extreme points of land to the outer crest of the bar. No stone will be necessary to weigh them down. The wood which forms their frame-work will outlast iron under water either salt or fresh. The *Teredo navalis* and other wood-eaters cannot reach them; for a single annual inundation, a cyclone, or the ordinary gales from the north and southeast, in a year after their completion, will bury them with batture from the river and sand from the Gulf. Two ribs of land 12 feet high above the level of the sea, densely covered with two lines of thrifty and beautiful trees and shrubs, will mark their graves, which will outlast the monuments of Egypt, and remain unmoved until "the trump of Doom" shall rend all tombs. The seaward points of the jetties may be advantageously *diverged* at the same angle with their *convergence* for a variety of useful purposes. They will in some instances gather the force of currents from the sea during storms, and aid by their influx and outflow the erosion of the bar, and the formation of land in the inner angles of the jetties on either side of the navigable channel, and strengthen the whole work; and their divergent sea-points may be suitably formed into light-houses, signal-stations, and forts to guard the pass. It would consume too much time to demonstrate the important fact, which I will simply state, that *by jetties thus angulated* it costs no more to obtain a depth of 60 feet across the bar of the Southwest Pass, or any other over which the same quantity of water flows, than it does to secure a channel 30 feet deep. If by the convergence of the jetty-points on the outer crest of the bar to a distance of 880 yards of each other the channel is scoured 30 feet deep, jetties of precisely the same dimensions and cost brought to *half the distance*, or 440 yards apart, will inevitably dredge one *twice the depth*, or 60 feet. They will force the current to do this without the aid of a dredge-boat; and they will maintain that depth of water without any assistance *forever* as long as it flows between them.

Converged jetties act as a *continual guard* to the channel. They deepen the trough and parallel the sides with its excavated materials. They are buried out of sight in the silt, and they remain concealed as long as the current flows in the trough which they have made. But if a sunken wreck or any obstacle in the channel shifts it to either side, the diagonals are uncovered by its erosion, and they act upon the current as they did at first, and again deflect it to its proper course.

I have not the space to show how the bars of the Amazon, Orinoco, and many other great rivers

have been removed and their deltas swept away by the combined action of the fluviatile and marine currents guided by natural diagonal jetties. The deposits of some of them, like those embraced between the great divergent jaws of the mouth of the Saint Lawrence opened widely to receive and accumulate the high tides of the Arctic current flowing along the eastern shore of British America, have all been scoured out to a bottom of solid rock, walled with the same material, swept bare of all earthy and soluble matters. Deep channels or straits, between continents and islands, are kept open by the deflected currents guided by their angulated shores. (See Plate III, Diagram 9.)

From all these facts the following conclusions are deduced, which I will only have time and space to give in the form of brief practical directions for the guidance of engineers. The same rules, varied by the genius and common sense of those who have to execute the work of controlling and utilizing water-currents, may be applied to any river, and especially to those parts of them which are unobstructed by rocky ledges, and whose beds are composed of sand, clay, and minutely-disintegrated matter, like the Mississippi from Cairo to the Gulf. They may also be applied to those which are obstructed by falls, and flow over beds of stone and between cliffs of rock; but in such cases the erosion caused by the properly-angulated jetties must be aided by blasting and cribwork of wood and stone. I will direct your attention exclusively to the Mississippi River from the mouth of the Ohio to the passes, and give these directions to accomplish the following important objects:

1. To open a navigable channel which at the lowest stage of water will have a depth of 30 feet, and which may be extended up the main tributaries to the Appalachian Chain and the Rocky Mountains.

2. To give permanence to the present banks of the river, and also to preserve those of its islands; or, in other words, to secure the boundary lines of the lands on its banks and islands from being cut and destroyed by the shifting of the current, and to confine the current to an unchanging bed, which will be only altered by being deepened. It will not be permitted to shift laterally, and it will be formed between the present banks, including those of the islands, so that no man's land will be lessened or injured by it. On the contrary, by contracting the width of the river the areas of the land fronting upon it in many instances will be greatly enlarged.

3. To utilize a general levee system which will be permanent, and which will make inundations by overflows, or crevasses by undermines impossible.

Direction 1.

Construct levees of earthwork on the most suitable ground for the purpose and the jetties to protect them simultaneously. The levees should be elevated above the high-water marks of the portions of the river to which they are applied, *and jetties at the same time should be built above every caving bend*, and not *in it*, extending from the top of the levee to the bottom current of the river. Rows of piles 12 feet apart and standing 8 feet apart in each row, with spike-wrapped fascines felted between, the piles placed and the brush packed, and the whole work girdled as I have already described, should be used where the depth of water does not exceed 40 feet. Their extension to a greater depth will have to be made with mattresses or caissons weighted with stone. The angulation of the jetties must be given to suit circumstances, and especially to direct the current to the points intended, and their effect will depend upon the skill of the engineer. If they are once built on this plan they will last through all future time.

Direction 2.

The river must be confined to a width of *half a mile*. The confinement by the jetties and the distances between their points must be proportioned to the size of each river. The Missouri for a distance of a thousand miles above its mouth must be confined to about a quarter of a mile in width. The Ohio, Arkansas, Tennessee, Red, Kansas, Cumberland, Washita, and Yazoo, and such rivers as the Rio Grande, Alabama, Brazos, and others, must be contracted to widths of from 100 to 250 yards, or to widths proportioned to the volumes of their waters. Channels should be blasted through the ledges of rock forming their falls and shoals, and dams of cribwork of wood and loose stones converged upon the channels to proper distances and at suitable angles. Cribbed-stone jetties must be applied where piles cannot be driven.

To effect this confinement of the Mississippi from Cairo or Saint Louis to the passes, it will not be necessary always to run the jetty points within a quarter of a mile of the central line of the channel they are intended to erode, but they should never approach each other nearer than a half mile. Where the river is very wide, shallow, and straight, it will sometimes be necessary to place them opposite to each other, and to converge their lines to a distance of half a mile between their points. But often short jetties, properly angulated, will greatly reduce the width of the river below them. In every instance where a properly-constructed jetty is run into the bottom current at an angle of 45°, it will deflect the current entirely across the bed against the opposite shore, unless the current deflected from another jetty extended from that shore strikes it diagonally before it reaches it. This is an important fact which should never be forgotten by hydraulic engineers, who must be required to *mingle the currents to prevent either of the two from reaching the shore opposite to its location.* The main object is to form them into an accumulated eroding current to deepen the bed, and to make batture against the banks. A properly-constructed jetty on one bank will certainly destroy the bank on the opposite side against which it points the current, unless another is suitably placed for its protection.

Direction 3.

Where it is necessary to scour a deep channel nearer one shore than the other, as in the case of a city front with its wharves, the jetties above the wharves must be deflected from the bank at very small angles, while those which guide the water from the opposite bank must have angles more obtuse, and in some instances they must have the maximum angulation of 45°. It must be remembered that the *minimum* angulation in all cases is 11¼°, and the *maximum* 45°, which is easily demonstrated by experiment. The angles of jetties to *turn cut-offs* like that at Vicksburg, and to close them, or to stop crevasses, must always be angulated from 22½° to 45°. (See Plate IV, Diagrams 1 and 2.

Direction 4.

To protect islands, construct at the upper end of each a V-shaped jetty with its point up stream, which will part the river current and deflect an eroding current toward each of the opposite banks. The eddies around the wings of the jetty will enlarge the island continually, while the currents which these wings deflect will undermine and destroy the banks unless jetties are placed upon them to catch the deflection and *reflect* it to a safe distance. If it is desirable to enlarge the island, the jetties on the opposite banks should be so angulated as to mingle the currents below it. It will extend until it reaches the point where the converged waters meet. If it is necessary to destroy the island, construct jetties on both banks above and opposite to it, to guide the currents against its sides from the upper to the lower end.

Direction 5.

To close a cut-off, bayou, or crevasse, first construct a jetty above it to deflect the current from its outlet from the river and form an eddy in it, and, if it is necessary, which will seldom be the case, assist the operation by a row of piles and fascines if it is shallow, or by sinking into it a connected raft of large trees with all their branches upon them down to the bottom if it is deep. I am not prepared to say precisely where such a work should be constructed to restore the river to its former channel in front of Vicksburg, as I have not examined the locality since the river has cut its way through the neck of the peninsula and left the city on the eastern curve of a crescent lake, and I have seen no chart of it since the destructive change occurred; but I am very confident that one or more jetties, constructed as all jetties should be, *at low water*, and at a suitable point on the right bank above the gap made by the new channel, would turn the whole river permanently against the rocks of the left bank and into its former bed. I cannot give an estimate of what it would cost the United States Government to make this improvement for this important harbor, as I have seen no topographical survey of it since the disaster happened, but I do not think that it would be much.

With this general outline of the titanic plan for chaining the mammoth river and utilizing its mighty current, I will close this essay, which I fear has been tedious, notwithstanding the omission of all specific details not necessary for its explanation.

To lower the whole bed of the Mississippi effectually, *the lowest bar should be removed first, and then those above should be destroyed successively or simultaneously* as high up as it is proposed to make it navigable, and to prevent its inundations. The river current, compelled to act permanently in a fixed channel, will deepen continually from age to age until its bed is conformed to the general slope of the continent from its highest navigable tributaries to its mouth in the Gulf. The inclination or dip of the strata of its bed-rock from the mountain crest to the deepest depressions of the Gulf determines the angulation of this slope. It would be madness to straighten its curves. Its velocity, caused by the earth's revolution on its axis, with its centrifugal force acting directly upon its vast volume, hurling it directly from the direction of the North Pole towards the Equator, would render it unnavigable and uncontrollable. Bends, changing this *direct* or *rectilinear action*, check its force. Our object should be to give fixedness to property on its banks, and to increase the area of its arable alluvial soil while we prevent its overflows, and at the same time make it safely and permanently navigable.

The excellence of this plan for controlling water-currents directed to cut channels of geometrical shapes by properly angulated jetties is made apparent by experiment. No dredging is necessary where the materials of the bottom are not more solid than the alluvium of the rivers and the sands and clays of our southern shores. In all places where these jetties are properly applied to make either river or sea currents deepen channels through such materials, in almost every conceivable instance of their application, they will form areas of *batture*, or new land, which will be worth much more than the entire cost of their construction. In order that these principles may be better understood and applied, I have directed the attention of engineers to the Mississippi, Lake Pontchartrain, and a few other points for the purpose of illustration. But if they possess ordinary genius, with even but little invention, they can easily vary and apply the same principles of angulation and *ekmuzesis* to any river, harbor, or marsh where there is water to employ and control. They who still cherish the absurdity taught me in my boyhood, that water, unlike other fluids composed of globules of atoms, *cannot be reflected*, of course cannot understand them, and will not attempt to utilize them.

CONCLUSION.

If the facts which I have presented, with the theories based upon them, in this essay, have given it the appearance to some minds of a harsh criticism upon the plans of hydraulic engineering applied by Sir Charles Hartley and other eminent engineers to the rivers and harbors of Europe and America, I say in all sincerity that I have not intended to detract any ray from their deserved renown, or to diminish the debt of gratitude due to them by mankind for their useful services. My object has been to give the improvements to all plans for controlling and utilizing the currents of rivers and seas which newly-discovered facts and useful inventions have suggested. I honestly desire to facilitate the tasks of these meritorious laborers for the welfare of the world, and to save them and those who will succeed them from much unnecessary toil and expense in their operations by presenting them with improvements which will make similar works, and others on a grander scale, cheaper, easier, and better. The latest discoveries made in the science of zoölogy, and in the arts of photography, telegraphy, and steam navigation only enhance the fame of Cuvier, Daguerre, Morse, and Fulton, and render their memories more dear to all nations as benefactors of the human race. I will only add that I tested all these inventions for controlling and utilizing water-currents, and which were made in order to cheapen the vast and permanent works for which they are designed, by the most careful and satisfactory experiments before I ventured to publish them in these lectures for the welfare of mankind.

May the God of all wisdom and power give them grace to use them wisely and successfully.